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Engineering Design File

PROJECT NO. 23833

OU 7-13/14 In Situ Grouting Project Foundation Grouting Study

Idaho National Engineering and Environmental Laboratory

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EDF No.: 5028 EDF Rev. No.: 0 Project File No.: 23833

1. Title: OU 7-13/14 In Situ Grouting Project Foundation Grouting Study

2. Index Codes:
Building/Type WMF-700 Subsurface Disposal Area SSC ID N/A Site Area Radioactive Waste Management Complex

3. NPH Performance Category: ________ or ☒ N/A

4. EDF Safety Category: ________ or ☒ N/A SCC Safety Category: Consumer Grade or ☒ N/A

5. **Purpose:** The purpose of this engineering design file is to determine the spacing requirements for placing in situ grouted columns in areas of the Idaho National Engineering and Environmental Laboratory Subsurface Disposal Area identified as having a long term potential for subsidence. The grouted columns will function to structurally support new and existing soil layers under a future soil and rock layered surface barrier. This grouted column support system is designed to prevent the propagation of waste/soil matrix subsidence to the top of the surface barrier.

Scope: The areas under consideration for foundation grouting include Pits 1 through 6, 9 through 12 and Trenches 1 through 10. Several mathematical soil models (created using the finite element analysis computer program PLAXIS) representing the above pits and trenches were analyzed. Initially, a 2-ft diameter grouted column was assumed for each model. Since, there is a potential for any grouted column to be as small as 1 ft in diameter, one representative soil model is re-analyzed using this dimension. Finally, in an effort to explore a potential increase to column spacing, a tightly spaced cluster of three, four, and five 1-ft diameter columns, respectively, that replaces each single column, is considered.

Acceptance Criteria: For each PLAXIS model, at the end of each simulated subsidence event or full seismic loading cycle, the following series of questions were evaluated considering the output results:
1. Do the analysis results indicate that any portion of the soil mass collapses?
2. Does the top surface of soil barrier deform in such a way that water ponding would be possible?
3. Is there a zone of tension created between the top surface and waste matrix such that a potential path for water infiltration is created?

If the answer to each question above is no, then the grout column spacing is deemed acceptable. If any answer is yes, either collapsing soil masses (if not needed for structural support) are removed or the grout column spacing is reduced, as appropriate. Then, the analysis model is rerun.

Results, Conclusions, Recommendations: The analysis results indicate that if a minimum of 1.5 ft of grading fill is provided in the area occupied by Trenches 1 through 10, no grouted columns are required in this area. For each of the pits, a column spacing of 12 ft on center maximum is required to meet the acceptance criteria outlined above.

For the case of 1-ft diameter columns, the results indicate no change to the 12-ft maximum spacing. For the case of a cluster of three columns, a triangular (versus a rectangular) grouting pattern is assumed to ensure equal spacing in each direction. Without a separate analysis, it is concluded that this case, along with the case of a four-column cluster, represents the same case as the 2-ft diameter column case, thus no change to the 12-ft maximum spacing is indicated. The five-column cluster, which would result in a pentagonal grouting pattern, results in a column width of approximately 3 ft. For this case, the results indicate that the column spacing may increase to 13 ft.

It is recommended that the future analyses consider the actual parameters of the soil and rock layers to be used for the surface barrier be established from standard soils testing. This can only be accomplished when actual soil and rock borrow sources are identified for the barrier construction. More accurate and refined analyses can be carried out at that time. At that time, it is also recommended that the advanced features of PLAXIS, such as the ability to increase modulus of elasticity with increasing depth, be employed to so that that the soil behavior may be more accurately predicted.

Further, it is recommended that the assumptions made for the soil properties of the existing overburden and the undisturbed soil areas be verified through standard soils testing.

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Finally, it is recommended that the final design of the surface barrier and grading fill consider the conclusions of this engineering design file.

6. Review (R) and Approval (A) and Acceptance (Ac) Signatures:
(See instructions for definitions of terms and significance of signatures.)

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FIGURES

ACRONYMS

DOE	Department of Energy
EDF	engineering design file
INEEL	Idaho National Engineering and Environmental Laboratory
PC	performance category
SB	surface barrier
SDA	Subsurface Disposal Area
TFR	technical and functional requirement

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OU 7-13/14 In Situ Grouting Project Foundation Grouting Study

1. PURPOSE

The purpose of this engineering design file (EDF) is to determine the spacing requirements for placing in situ grouted columns in areas of the Idaho National Engineering and Environmental Laboratory (INEEL) Subsurface Disposal Area (SDA) identified as having long-term potential for subsidence. The grouted columns will function to structurally support new and existing soil layers under a future soil and rock layered surface barrier (SB). This grouted column support system is designed to prevent the propagation of waste/soil matrix subsidence to the top of the SB.

2. BACKGROUND

The SDA is a radioactive waste landfill containing hazardous chemicals, remote-handled fission and activation products, and transuranic radionuclides. These wastes, in the form of stacked or randomly dumped boxes, drums, and loose waste have been disposed of in pits, trenches, soil vaults, and an asphalt pad since 1952 (see Figures 1 and 2). In general, underburden soil with an approximate average depth of 2 ft was placed into a pit, trench, or vault before filling it with waste. After substantial filling of each pit, trench, vault, or pad, overburden soil varying in depth from 2 to 9 ft was placed over each disposal unit (Holdren et. al 2002). This has been the state of the SDA for the past several years.

Currently, however, Pits 18, 19, and 20 are still receiving low-level waste. The plan is to eventually fill these pits also (with mostly boxed and stacked waste) and place overburden soil on these pits as well.

An engineered, layered, soil and rock SB (in addition to any overburden soil that currently exists on top of the waste) has been identified as a fundamental element of the end state for the landfill.[a] The three main functions of the SB are to minimize water flux, provide a mechanism to vent landfill gasses, and to inhibit plant and animal intrusion. A preliminary design for the SB, described as an evapotranspiration/biobarrier cover, is proposed and discussed in detail in ICP/EXT-04-00216.[b] A cross section showing the various layers proposed is shown in Figure 3. The grading fill, which is a soil layer of varying thickness, is placed directly on the existing overburden soil (and directly below the biointrusion barrier) and serves to create a slope appropriate to shed the moisture expected in the form of rainfall and snowmelt. The rate of slope selected considers a balance between the amount of water required to shed and the need to avoid erosion because of runoff water velocity.

Another essential performance criterion of the SB is that the design must accommodate potential subsidence. Although general subsidence is not considered a significant problem, differential subsidence is considered a significant potential problem. Since the potential for differential subsidence is high in the SDA because of large differences in bulk densities and disposal methods of adjacent waste/soil

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a. Mattson, E, D., M. D. Ankeny, S. Dwyer, N. Hampton, G. Matthern, B. Pace, A. Parsons, M. Plummer, S. Reese, and J. Waugh, 2004, *Preliminary Design Criteria and Cover Evaluation for the INEEL Subsurface Disposal Area (DRAFT)*, ICP/EXT-04-00216.

b. Mattson, E, D., M. D. Ankeny, S. Dwyer, N. Hampton, G. Matthern, B. Pace, A. Parsons, M. Plummer, S. Reese, and J. Waugh, 2004, *Preliminary Design Criteria and Cover Evaluation for the INEEL Subsurface Disposal Area (DRAFT)*, ICP/EXT-04-00216.

combinations[c] (Zitnik et al. 2002; Hiaring, Horton, and Schlafman 1992), an additional measure to either prevent subsidence or isolate the SB from the effects of subsidence is deemed necessary.

One method currently under consideration is dynamic compaction, which would accelerate the consolidation of the waste matrix and reduce the potential for future subsidence.[d] Dynamic compaction tests and monitored operations involving actual waste have been used with success at other Department of Energy (DOE) sites (EDF-4909 2004). This method has been assessed for use at the SDA and is discussed with recommendations in EDF-4909, "Assessment of Dynamic Soil Compaction at the SDA."

An alternate method, in situ grouting, uses a roto-percussion type drill rig to inject high-pressure grout into the ground to form columnar structures (approximately 1 to 2 ft in diameter) at a specified spacing. This type of in situ grouting, hereinafter referred to as foundation grouting, is identified as a potential method for structurally supporting the SB, thus protecting it from the effects of detrimental differential subsidence of the waste matrix. A rendered cutaway sketch of a typical pit with emplaced grout columns is shown in Figure 4. Another type of grouting, referred to as contaminant grouting, uses the same method as foundation grouting, but seeks to achieve a different purpose. In contaminant grouting, grout columns are placed very close together so that each column overlaps a portion other columns previously placed. The final grouted volume forms a monolith of a waste/soil/grout mixture and effectively removes the potential for the migration of the harmful constituents out of the waste into the environment. A secondary benefit to contaminant grouting is the continuous structural support that it provides for the future SB.

3. SCOPE

The technical and functional requirements (TFRs) defined by the In Situ Grouting Project (TFR-267 2004) state that foundation grouting shall be considered for Pits 1 through 6 and 9 through 12, and Trenches 1 through 10. These areas are generally the locations where the majority of the Rocky Flats Plant transuranic wastes that were shipped to the INEEL were disposed of (see Figure 5). Other pits and trenches in the SDA will also be grouted, but these areas will be contaminant grouted. Because of this method of grouting, long-term subsidence is not a concern in these areas. This EDF determines the center-to-center spacing of idealized 2-ft diameter, cementitious grout columns for the various areas identified above. (The 2-ft diameter dimension was selected as a target diameter.) Because of variations in grout formulation, grout injection pressure, and soil/waste bulk densities, there is a potential that some columns may end up as small as 1 ft in diameter. For this reason, each analysis model is rerun with 1-ft diameter columns to ensure the acceptance criteria outlined below is still met. The loads considered include the combination of gravity and seismic loads as defined below. The resulting maximum combined axial and bending stresses are investigated and the minimum compressive strength for the grout column is recommended.

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c. Mattson, E, D., M. D. Ankeny, S. Dwyer, N. Hampton, G. Matthern, B. Pace, A. Parsons, M. Plummer, S. Reese, and J. Waugh, 2004, *Preliminary Design Criteria and Cover Evaluation for the INEEL Subsurface Disposal Area (DRAFT)*, ICP/EXT-04-00216.

d. Mattson, E, D., M. D. Ankeny, S. Dwyer, N. Hampton, G. Matthern, B. Pace, A. Parsons, M. Plummer, S. Reese, and J. Waugh, 2004, *Preliminary Design Criteria and Cover Evaluation for the INEEL Subsurface Disposal Area (DRAFT)*, ICP/EXT-04-00216.

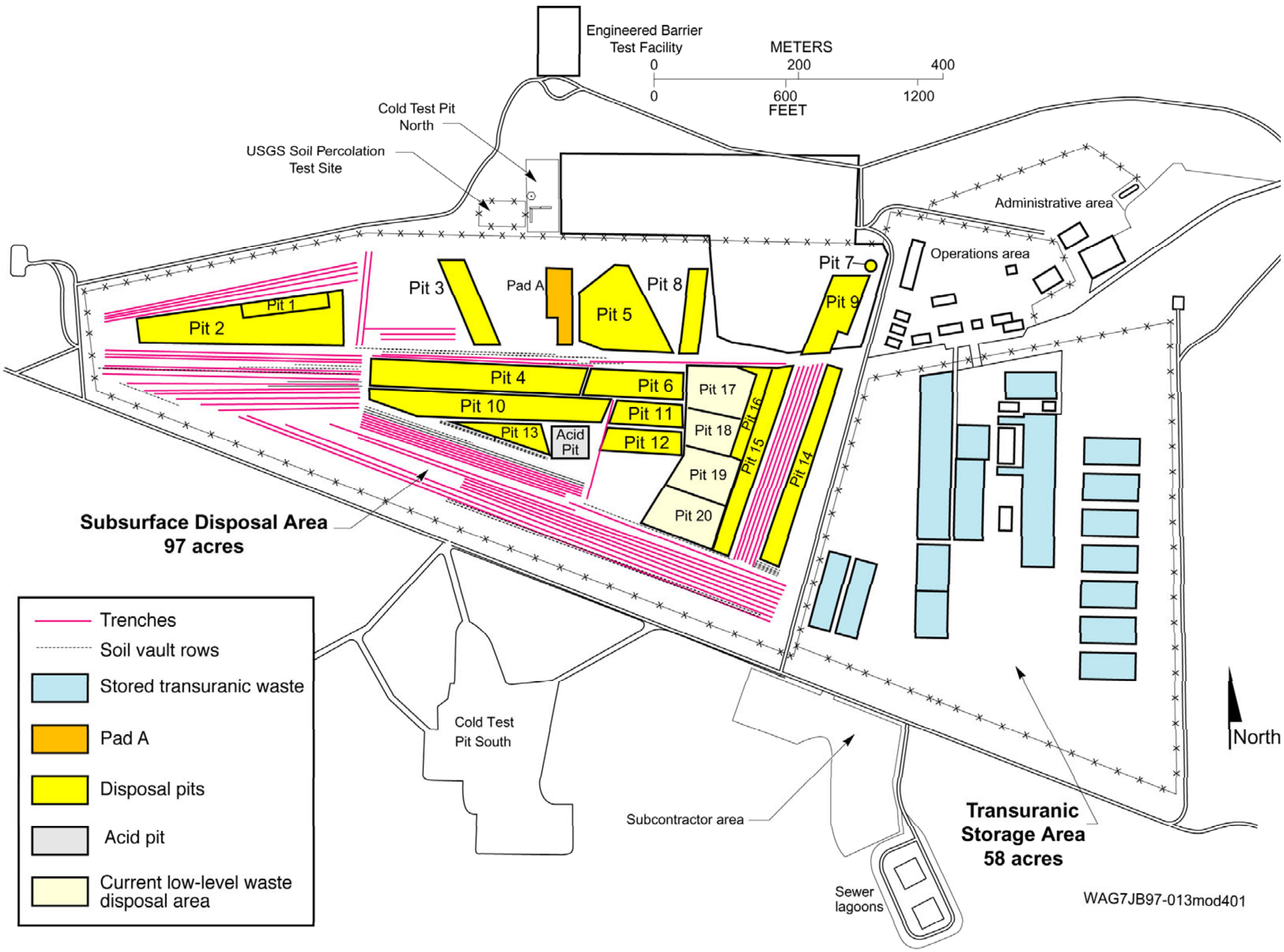

Figure 1. Map of the Radioactive Waste Management Complex, showing the location of the Subsurface Disposal Area.

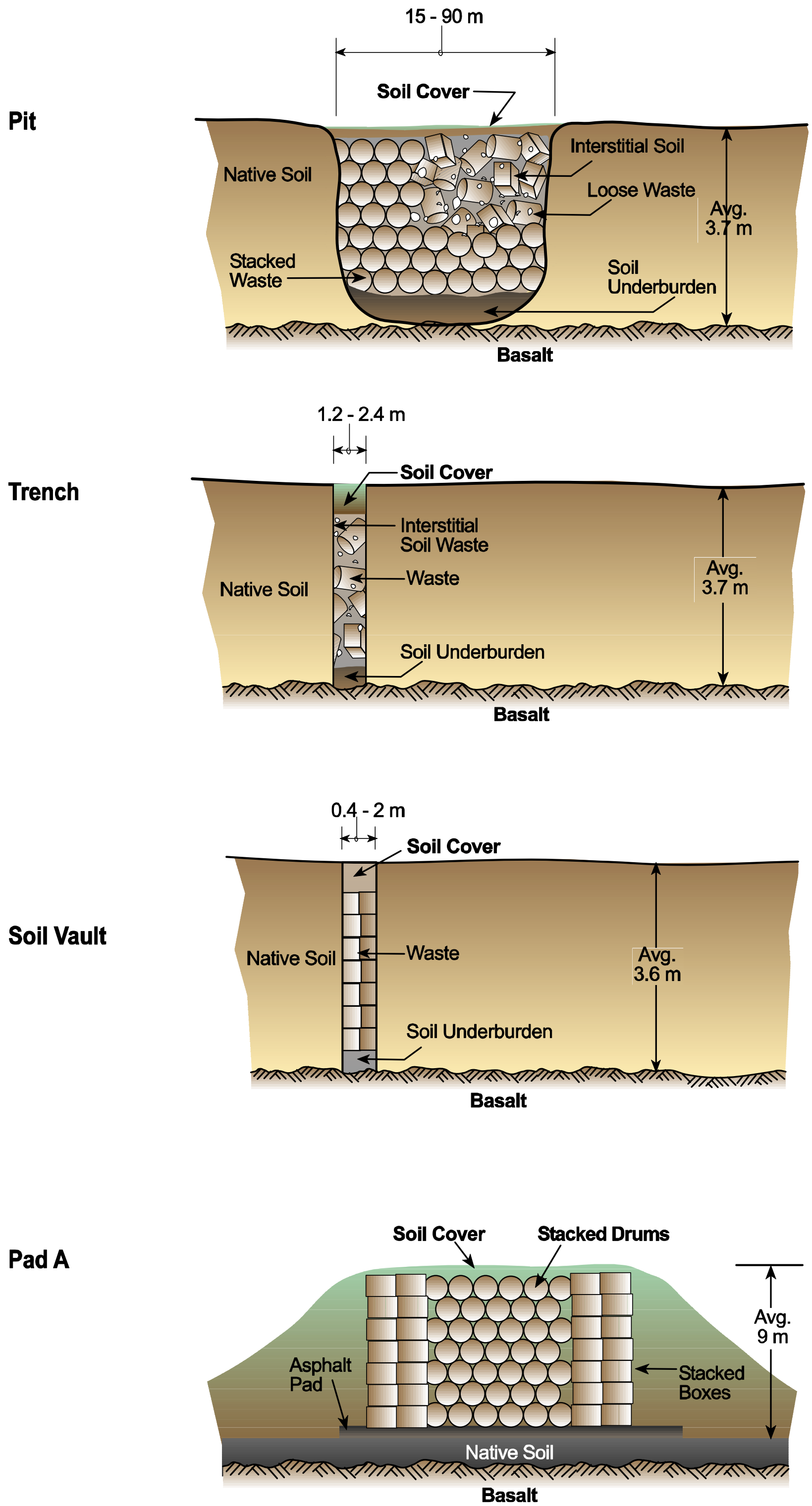

Figure 2. Cross sections of typical waste pit, trench, vault, and Pad A within the Subsurface Disposal Area located at the Radioactive Waste Management Complex.

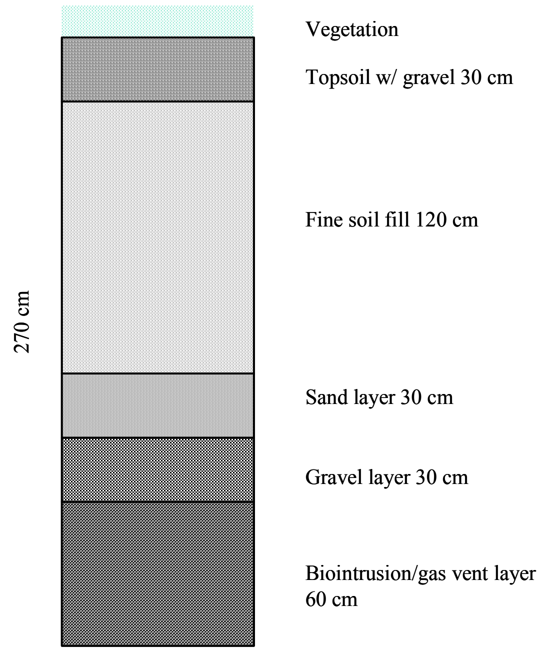

Figure 3. Cross section of the evapotranspiration/biobarrier cover.

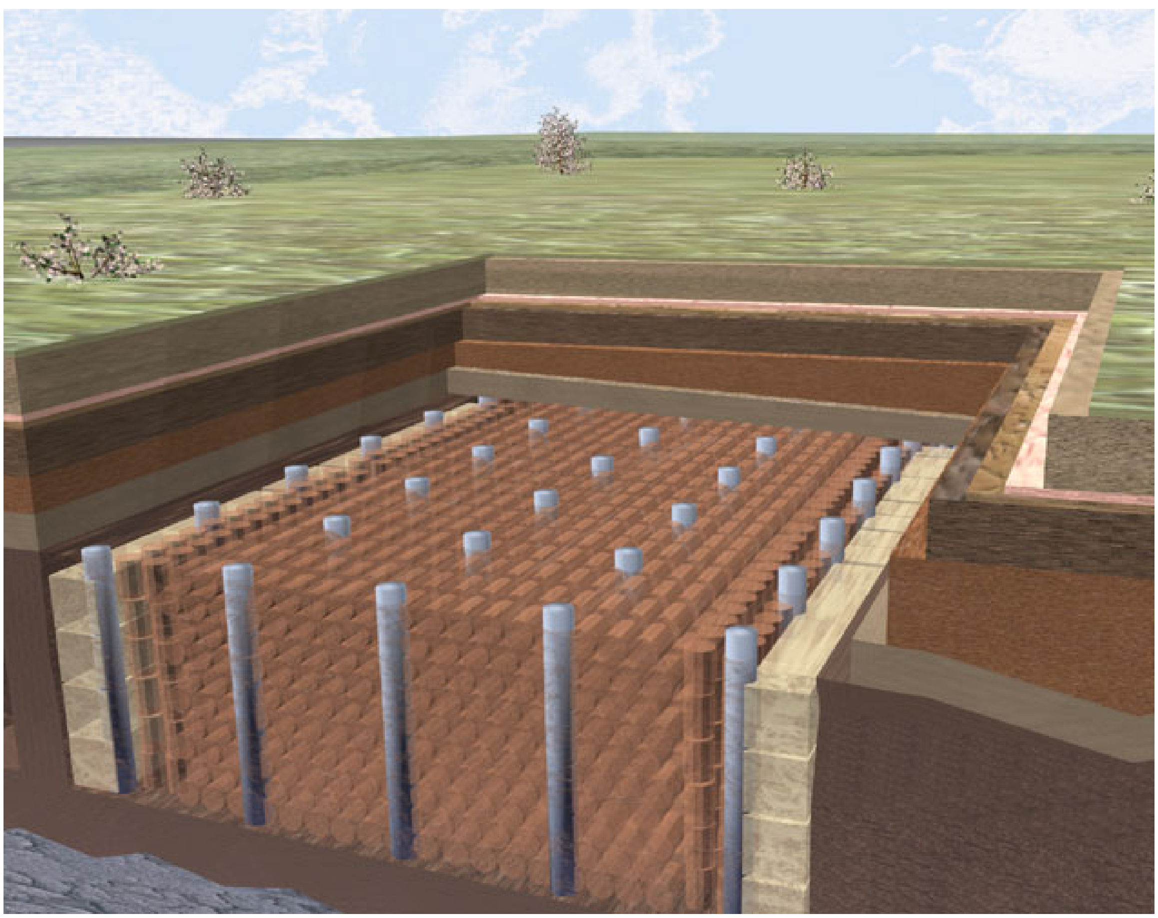

Figure 4. Rendered cutaway sketch of grouted columns in a typical Subsurface Disposal Area pit.

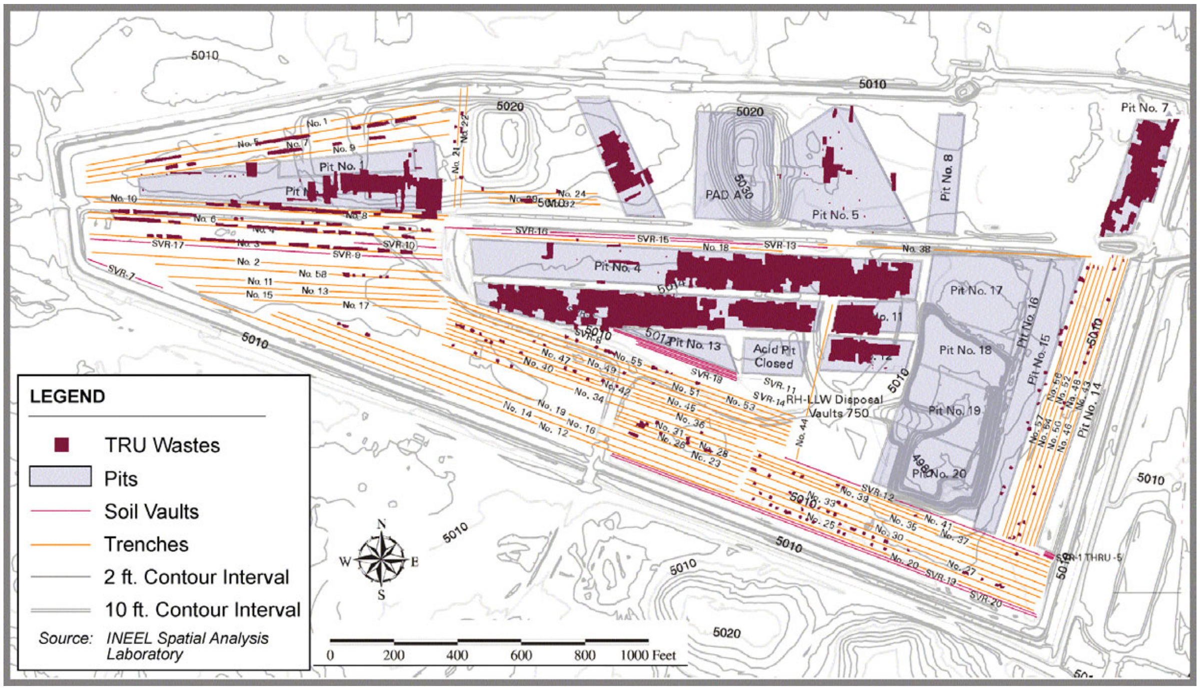

Figure 5. Subsurface Disposal Area waste disposal units.

4. REQUIREMENTS

TFR-267, “Requirements for the OU 7-13/14 In Situ Grouting Project (Customer, Project, and System),” states that all of the above listed pits and trenches shall be foundation grouted for the purpose of preventing subsidence or breach of the top surface of a future SB unless one of the following conditions precludes the need to perform foundation grouting: 1) the pit or trench portion is ultimately stabilized with contaminant grouting, 2) the pit or trench portion has been or will be retrieved and backfilled with soil, or 3) a pit or trench portion is determined, by analysis or test, to no longer require foundation enhancement in order to support the SB.

5. SAFETY CATEGORY AND NATURAL PHENOMENA

Per TFR-267, Section 2.2, the safety category for this analysis is consumer grade. For this conceptual analysis, it was determined by the project team that the analysis should consider the effect of the design basis seismic event corresponding to a Performance Category-2 (PC-2). Thus, the combination of gravity and applicable seismic loads are considered herein.

6. ANALYSIS APPROACH

The analytical approach used to evaluate potential spacing for grouted columns in the above pits and trenches included the use of the computer program PLAXIS (PLAXIS 8.2). PLAXIS is a specialized finite element analysis program that uses the physical and mechanical properties of the soil to predict soil stresses and deformations under specified loading conditions. PLAXIS is a 2-D program only, suitable for use in solving plane strain or axisymmetric type problems. For this reason, cross-sectional areas representative of the trenches and of the pits were created. In an effort to bracket the various combinations of grading fill (proposed in the preliminary SB design) and overburden soil depth, areas to be modeled were selected at the edge and near the east-west centerline of the SDA where both trenches and pits are located. In each case, an appropriate range of depths was modeled for the existing overburden soil depths and a minimum depth modeled for the grading fill. The following models were created, analyzed, and represent the scope of this EDF:

1. TrenchTrans 1 is a 100-ft long cross section near the edge of the SDA, including Trenches 1, 5, 7 and 9. Overburden depth is 2-ft thick (min) and grading fill depth 1.5- to 3.0-ft thick (see Appendix B, Figure B-1).

2. TrenchTrans 2 is a 100-ft long cross section near the centerline of the SDA, including Trenches 4, 6, 8, and 10). Overburden depth is 2-ft thick (min) and grading fill depth 5.5- to 7-ft thick (see Appendix B, Figure B-2). This model is also considered to represent Trenches 2 and 3.

3. General Pit 1 is a 46-ft cross section near the edge of the SDA, including Pits 1, 2, 3, 5, and 9). Overburden depth is 4-ft thick (min) and grading fill depth 1.5-ft thick (see Appendix B, Figure B-3).

4. General Pit 2 is a 46-ft cross section near the centerline of the SDA, including Pits 4, 6, 10, 11, and 12). Overburden depth is 4-ft thick (min) and grading fill depth 10-ft thick (see Appendix B, Figure B-4).

5. General Pit 3 is a 46-ft cross section roughly between the centerline and south boundary of the SDA, including Pits 17, 18, 19, and 20). Overburden depth is 2-ft thick (min) and grading fill depth 6 ft (see Appendix B, Figure B-5).

The analysis process involved first creating the geometry, including layer width and thickness. Next the boundary conditions were established. For the above models, the boundary conditions were simply that movement was restrained in the lateral direction at each model's vertical sides and that movement was restrained in the vertical direction at each model's base (i.e., basalt layer). Next, the vertical grout column elements were added at trial spacings. The program actually treats the columns as thick vertical plates with specified axial and bending stiffnesses. See Appendix A for calculations determining the stiffnesses that represent a grouted column. In order to ensure the full width of the top of the column is modeled correctly, a 2-ft (or 1-ft) wide structural plate element is added perpendicularly to each column element. In addition, a 4-in. diameter, shorter grout column is added to the top of each grout column to represent the formation of grout returns filling the void created by the drill stem.

The model is then meshed with 15-node triangular elements. The soil layers, as well as the structural elements, are incorporated into one mesh in order to account for soil-structure interaction. Next, the snow load is defined as a 35-psf load on the ground surface (this meets the design snow load required by DOE Architectural Engineering Standards). A preliminary analysis is then performed to determine the initial stresses in the soil based on gravity loading only. These initial stresses then form the basis as the initial condition for the subsequent analysis stages.

One of the useful features of PLAXIS is the ability to analyze a model at each stage of construction or at each change to the physical condition of a soil model over a period of time. Soil masses, as well as structural elements, are defined during the geometry creation and can be set to be included or excluded (i.e., activated or deactivated) at any analysis stage. The stresses and deformations calculated at each stage are used as starting points for each subsequent analysis stage. Thus, the effect of stresses and deformations accumulating over time can be evaluated. To use this feature the following stages were defined and are considered to be representative of a worst case loading condition for the pits and trenches in the SDA.

Stage 1: Initial condition just after the injection of grout columns.

Stage 2: After construction of the SB with full snow load.

Stages 3, 4, 5, and 6: After design basis seismic event (see calculations in Appendix A for load combination definition) with no subsidence (includes full snow load).

Stage 7: After subsidence of approximately 2 ft over the entire area of model (includes full snow load).

Stage 8: After subsidence of 3 additional ft (5 ft total) over the entire area of the model (includes full snow load). Keck and Seitz (2002) predict moderate to high potential for future subsidence and estimate a maximum average subsidence depth of 5 ft.

Stage 9, 10, 11, and 12: After second design basis seismic event under full subsidence conditions and full snow load.

During Stage 7 or later, there is a potential for either all or a portion of a soil mass to collapse. If this happens, the calculation process terminates with a message indicating that a soil mass has collapsed. At this point, however, the graphical results can be examined to see where the failure occurs. From this information, the geometry can be modified to allow removal of just these collapsing portions from subsequent analysis runs. Once these portions are removed, the analysis stages are rerun. The resulting internal stresses redistributed in a way that soil bridging occurs, as in the first run, but since previously collapsing portions are no longer present they do not cause the program to terminate. Thus, this process follows an iterative process to predict the soil bridging behavior of the various soil layers making up the SB.

If the program completes the analysis of all stages successfully, the final stage is examined for maximum deflection of the top surface and for any zones of tension from the top surface to the top of the sand layer. Zones of tension would indicate potential areas of soil cracking which would allow surface water to concentrate and develop detrimental flow patterns into deeper sections of the SB. If either of these items does not meet the acceptance criteria defined below, the grouted column spacing is reduced and the entire process is repeated.

7. ASSUMPTIONS

The following were determined to be assumptions for the foundation grouting study for the In Situ Grouting Project:

- The SB will cover the entire SDA. The SB design used in this EDF is based on the preliminary design described in the ICP/EXT-04-00216.[e] The surface barrier will be multilayered but of constant thickness, while the grading fill depth will vary from 10 ft near the center of the SDA to approximately 1 ft near the perimeter.

- Borrow sources for the various layers of the SB were not finalized at the time of this report. Thus, values for soil strength and stiffness parameters used in the calculations were assumed based on expected borrow sources and/or median values as published in various soil or foundation engineering textbooks. See Appendix C for more information. A final analysis shall be performed

e. Mattson, E, D., M. D. Ankeny, S. Dwyer, N. Hampton, G. Matthern, B. Pace, A. Parsons, M. Plummer, S. Reese, and J. Waugh, 2004, *Preliminary Design Criteria and Cover Evaluation for the INEEL Subsurface Disposal Area (DRAFT)*, ICP/EXT-04-00216.

once the borrow sources have been determined and all soil properties values needed for the analysis have been established. Strength and stiffness values for waste and soil/waste parameters were also assumed since no source of this type of data has been identified to date. However, for this EDF, conservative assumptions were made in the case of the waste since very little strength or stiffness can be counted on because of the nature of the waste forms occurring in the SDA. Strength and stiffness parameters for existing soil surrounding the pit and trenches were assumed to be the same as that determined recently by INEEL soil testing of overburden soils from Pit 4 (Liquid and Plastic Limits Test Report 2004). All parameters, whether assumed or based on soil testing, are tabulated in Appendices D through H.

- The soil cover will crown along an approximate east-west SDA centerline. The surface will slope down from the east-west centerline at approximately 1.5% to the north and south. The surface will also slope slightly in the north-south direction in order to transition to a minimum fill thickness at the SDA's east and west boundary. The minimum grading fill depth at any pit or trench is assumed to be 1 ft.

- The existing overburden soil depth varies from 2 to 9 ft over the SDA (Holdren et al. 2002). Each pit or trench has generally the same depth of overburden, but the depth can vary widely over a single pit or trench. The existing overburden, its depth, strength, and stiffness, is a very important element in determining the ultimate grouted column spacing for structural support of the SB. As for the soil and rock layers of the SB itself, values for soil strength and stiffness parameters for the existing overburden are based on recent testing done for an area of Pit 4 (Liquid and Plastic Limits Test Report 2004). A final analysis shall be performed once the actual soil property values for overburden soils over the other pits and trenches have been established. The manner in which the elevation of the surface of the waste/soil matrix varies is assumed. See Zitnik et al. (2004) for tabulation of estimated existing overburden soil depths. The range of overburden depths is taken into account by randomly varying the surface of the waste so that the maximum and minimum overburden depths occur within a single model.

- Each grout column is assumed to be placed perpendicular to the existing overburden soil; have an idealized, uniform, circular cross section; and rest on a relatively unyielding substrate, such as bedrock. The size and shape of each column is assumed to stay the same over the life of the project. Some limited variance in perpendicularity may be tolerated because of a seismic event or other forces, but this variance is not expected to be significant.

- Each column is assumed to extend from a basalt layer (unyielding) to a point in the existing overburden. This point is conservatively assumed to be 1 ft above the surface of the waste matrix when existing overburden is 2 ft thick or less. For thicker overburden layers, this point is assumed to be 2 ft above the surface of the waste matrix. Grout returns 4 in. in diameter are assumed to fill the annulus created by the drill stem between the top of the grout column and the top of the existing overburden.

- A DOE performance category per DOE-STD-1021, "Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components," has not yet been determined for this project. Due to the nature of the determination of column spacing required to support a future SB, it is felt that a design basis seismic event should be included in the design load combinations considered in this EDF. Thus, it is conservatively assumed that a DOE PC-2 with its corresponding seismic loading criteria applies to this project.

8. ACCEPTANCE CRITERIA

Each soil model with its various stages as described above was analyzed. At the end of each stage or full seismic loading cycle, the following series of questions were evaluated based on the output results. If the answer to each question was negative, then the spacing was deemed acceptable.

1. Do the analysis results indicate that any portion of the soil mass collapses? If no, go to question 2. If yes, isolate collapsing soil mass (if possible), artificially remove these sections, and re-evaluate.

2. Does the top surface of the soil barrier model deform in a way that water ponding would be likely? A deflection of 1 in. or less at any point is considered acceptable. If no, go to question 3. If yes, reduce spacing and re-evaluate.

3. Is there a continuous zone of tension created between the top surface and sand layer, creating a potential path for water infiltration? If no, spacing is considered acceptable. If yes, reduce spacing and re-evaluate.

9. RISKS

The following were determined to be risks for the foundation grouting study for the In Situ Grouting Project:

- Not being able to begin the column formation at a permanently unyielding surface (basalt)

- Not being able to form at least a 1-ft diameter grout column

- Stopping the formation of the grout column below the waste-overburden interface

- Stopping the formation of the grout column higher approximately 1 ft above the waste-overburden interface.

10. RESULTS

PLAXIS generates detailed reports in Microsoft Word format. General information, geometry, loads and boundary conditions, mesh data, and selected results are included in Appendices D through H for the models listed in Section 6, respectively. In order to limit the number of pages of output, only the results from the significant stages (or phases) are included in this report. Significant stages are considered to be Stages 2, 8, and 12. See the description of the stages in Section 6.

11. CONCLUSION

1. TrenchTrans1: A first run with no grouted columns in any of the trenches indicated that the soil mass collapses above Trench 1 only (see Figure 6).

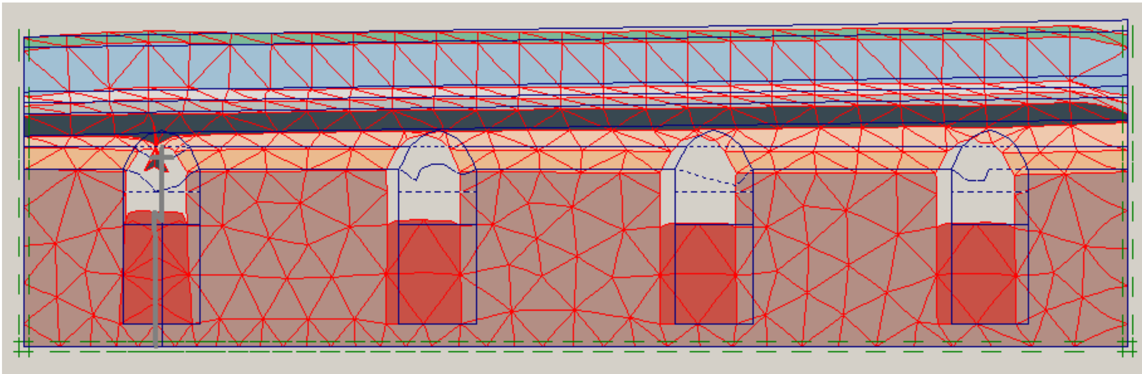

Figure 6. Deformed mesh of a 100-ft cross section depicting Trenches 1, 5, 7, and 9 (left to right), showing failure at Trench 1 when grading fill is 1-ft deep at left edge (west side of the Subsurface Disposal Area).

Thus, in an effort to support Trench 1, a grouted column along its centerline was modeled for subsequent analysis runs. This solution was successful in supporting the surface barrier, but created a questionable area of tension within the surface barrier above Trench 1 (see Figures 7 and 8).

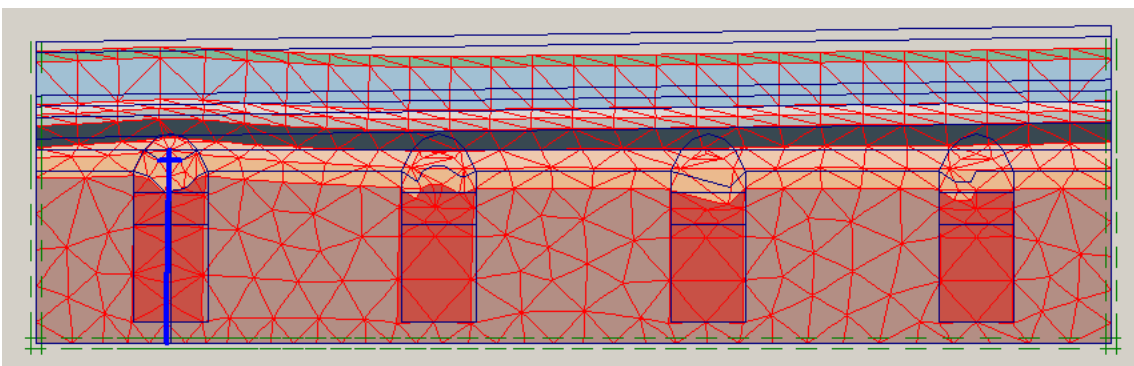

Figure 7. Deformed mesh of a 100-ft cross section depicting Trenches 1, 5, 7, and 9 (left to right), showing failure at Trench 1 when grading fill is 1-ft deep at left edge (west side of the Subsurface Disposal Area).

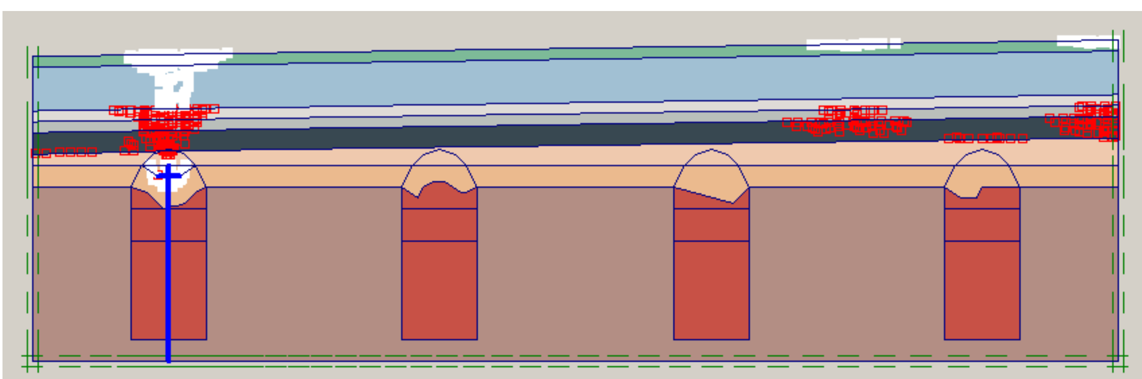

Figure 8. Plot of soil tension points (i.e., white squares) of a 100-ft cross section depicting Trenches 1, 5, 7, and 9 (left to right), showing failure above Trench 1 when grading fill is 1-ft deep at left edge (west side of the Subsurface Disposal Area) and only Trench 1 is grouted.

This problem was corrected by specifying a 6-in. increase in grading fill layer, deactivating (removing) the grouted column, and running the analysis again. This time, all acceptance criteria were met on this run (see results for TrenchTrans1 in Appendix D). Thus, no grouting is required for the trenches modeled when the grading fill minimum depth is 1.5 ft at the location shown. This location is approximately 13 ft to the north of the centerline of Trench 1.

2. TrenchTrans2: No foundation grouting is required. The size and shape of the trenches in combination with the depth of existing overburden and grading fill are such that soil bridging occurs under subsidence conditions. This remains true during and after the design seismic event (see Appendix E).

3. General Pit1: Grouted columns are required at 12-ft spacing each way. Minimum depth of grading fill at any location above the pit is 1.5 ft (see Appendix F).

4. General Pit2: Grouted columns are required at 12-ft spacing each way. Minimum depth of grading fill at any location above any pit is 1.5 ft. This will not be difficult to achieve for the pits represented with this model because of expected minimum grading fill slope (see Appendix G).

5. General Pit3: Grouted columns are required at 12-ft spacing each way. Minimum depth of grading fill at any location above any pit is 1.5 ft. This will not be difficult to achieve for the pits represented with this model because of expected minimum grading fill slope (see Appendix H).

An overall plan of the SDA showing areas to be foundation grouted is shown in Appendix I. Areas within pits that are not to be foundation grouted are either areas that either have been or will be retrieved and backfilled or are areas that are occupied by low-level waste concrete disposal vaults.

12. RECOMMENDATIONS

It is recommended that the future analyses consider the actual parameters of the soil and rock layers to be used for the SB be established from standard soils testing. This can only be accomplished when actual soil and rock borrow sources are identified for the barrier construction. More accurate and refined analyses can be carried out at that time. At that time, it is also recommended that the advanced features of PLAXIS, such as the ability to increase modulus of elasticity with increasing depth, be employed to so the soil behavior may be more accurately predicted.

Further, it is recommended that the assumptions made for the soil properties of the existing overburden and the undisturbed soil areas be verified through standard soils testing.

Finally, it is recommended that the final design of the SB and grading fill consider the conclusions of this EDF.

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Appendix A

Calculations

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Appendix A
Calculations

Seismic Load (IBC Section 1615.1.2)

$S_s := 0.357$ $S1 := 0.131$ $I_p := 1.25$ (Seismic Use Group II assumed, Table 1604.5)

$W_p := 1.0 \cdot lb$ $F_a := 1.2$ (Soil Site class C assumed, see DOE Architectural Engineering Standards, Section 0200, Table 0200-2 and IBC Table 1615.1.2(1))

$S_{MS} := F_a \cdot S_s$ (Eq. 16-16)

$S_{DS} := \frac{2}{3} \cdot S_{MS}$ $S_{DS} = 0.286$ (Eq. 16-18)

$F_p := S_{DS} \cdot I_p \cdot W_p$ $F_p = 0.36W_p$ (0.36 g used within PLAXIS where horizontal acceleration input called for)

Snow Load

A ground snow load of 35 pounds per square foot shall be used per DOE Architectural Engineering Standards, Section 0111-6.

Load Combinations

Per IBC 2000, Section 1605.3.2, the following load combinations are applicable:

1. Dead + Snow
2. Dead + Snow + E/1.4

From IBC Section 1617:

Where the effects of gravity and the seismic ground motion are additive, the seismic load E (for a unit weight of 1.0 lb) shall be taken as:

$$E_{add} := \rho \cdot Q_E + 0.2S_{DS} \cdot \text{Dead} \qquad \text{(Eq. 16-28)}$$

Substituting Fp for Q_E, 1.0 for ρ, and solving yields the following:

$$E_{add} := F_p + 0.057 \cdot \text{Dead}$$

Where the effects of gravity and the seismic ground motion counteract, the seismic load E (for a unit weight of 1.0 lb) shall be taken as:

$$E_{counter} := \rho \cdot Q_E - 0.2S_{DS} \cdot \text{Dead} \qquad \text{(Eq. 16-29)}$$

Substituting Fp for Q_E, 1.0 for ρ, and solving yields the following:

$$E_{counter} := F_p - 0.057 \cdot \text{Dead}$$

Substituting and collecting terms for the combination including seismic loads yields the following two cases for seismic.

1. 1.04*Dead + Snow + 0.71*Fp
2. 0.96*Dead + Snow + 0.71*Fp

It is clear that for the current problem load case 1 is the most severe. Other than when simple gravity loads acting alone are considered, this load case is used in the analysis program (Plaxis) when both gravity and seismic loads are applied.

Grouted Column Stiffness

In order to take into account the structural properties of each grouted column, Plaxis requires input of four engineering parameters for the columns: 1) axial stiffness, E*A; 2) bending stiffness, E*I; 3) unit weight; and 4) Poisson's ratio, ν. The E is Young's Modulus (Modulus of Elasticity), the A, is cross sectional area. w, (ft^2), and the I is moment of inertia (ft^4). These parameters are calculated and listed as follows:

$f_c := 1200 \cdot psi$ (assumed minimum in-place grout compressive strength)

$E := 57000 \cdot \sqrt{\frac{f_c}{psi}} \cdot psi$ $E = 1974538 psi$ $E = 284333461 psf$ (Ref. 17, Section 8.5)

For 0.34 ft, 1.0 ft and 2.0 ft grout column diameters, respectively (the 0.34 ft diameter is calculated only to account for the area of grout returns above any column):

$A_{0.34} := \pi \frac{(.34 \cdot ft)^2}{4}$ $A_{0.34} = 0.091 ft^2$

$A_{1.0} := \pi \frac{(1.0 \cdot ft)^2}{4}$ $A_{1.0} = 0.785 ft^2$

$A_{2.0} := \pi \frac{(2.0 \cdot ft)^2}{4}$ $A_{2.0} = 3.142 ft^2$

$w := 130 \cdot \frac{lb}{ft^3}$ (asssumed maximum for grout/soil/waste mixture)

$I_{0.34} := \frac{\pi \cdot (0.17 \cdot ft)^4}{4}$ $I_{0.34} = 0.00066 ft^4$

$I_{1.0} := \frac{\pi \cdot (0.5 \cdot ft)^4}{4}$ $I_{1.0} = 0.049 ft^4$

$I_{2.0} := \frac{\pi \cdot (1.0 \cdot ft)^4}{4}$ $I_{2.0} = 0.785 ft^4$

$E \cdot A_{0.34} = 25815211\,lb$ $\quad$ $E \cdot I_{0.34} = 186515\,lb \cdot ft^2$

$E \cdot A_{1.0} = 223314978\,lb$ $\quad$ $E \cdot I_{1.0} = 13957186\,lb \cdot ft^2$

$E \cdot A_{2.0} = 893259911\,lb$ $\quad$ $E \cdot I_{2.0} = 223314978\,lb \cdot ft^2$

$\nu := 0.15$ (assumed, typical for concrete)

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Appendix B

Model Sketches

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Appendix B

Model Sketches

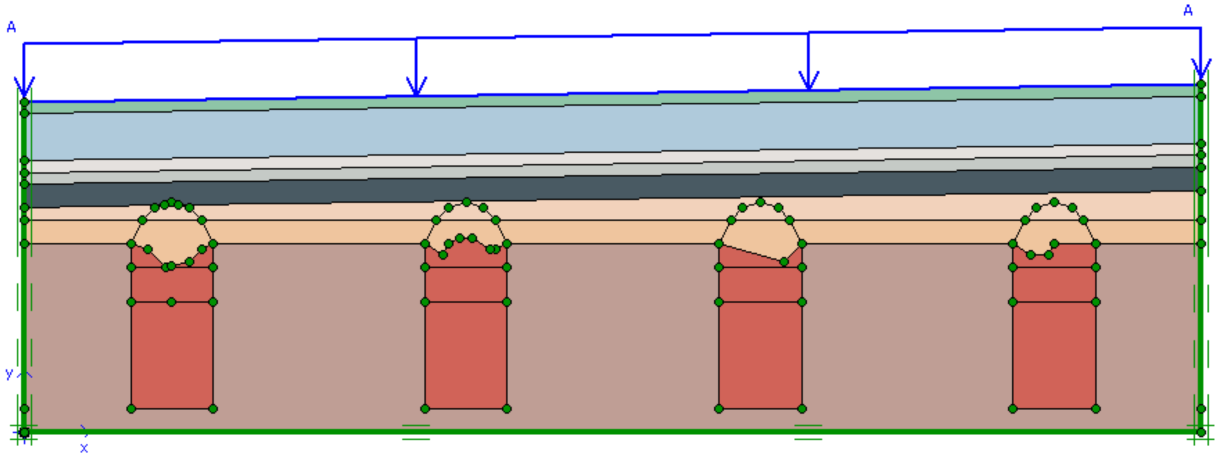

Figure B-1. Model TrenchTrans1a. 100-ft wide cross section across trenches 1, 5, 7, and 9 (moving left to right). Grading fill is 1-ft thick minimum.

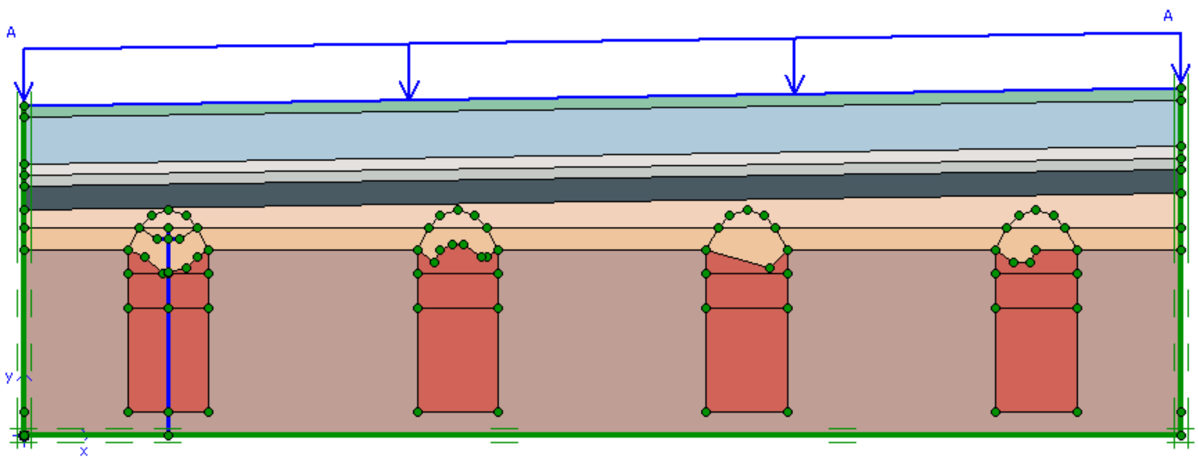

Figure B-2. Model TrenchTrans1b. 100-ft wide cross section across trenches 1, 5, 7, and 9 (moving left to right). Grading fill is 1.5-ft thick minimum. The representation of a grouted column is shown in trench 1.

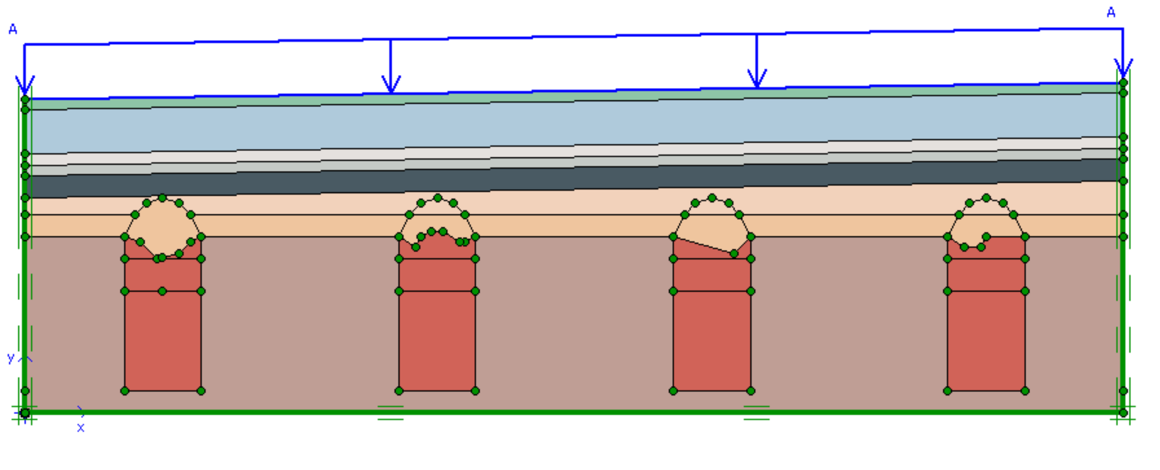

Figure B-3. Model TrenchTrans1c. 100-ft wide cross section across trenches 1, 5, 7, and 9 (moving left to right). Grading fill is 1.5-ft thick minimum. The representation of a grouted column shown in Figure B-2 has been removed. This configuration meets the acceptance criteria and no grouted columns are required at any trench.

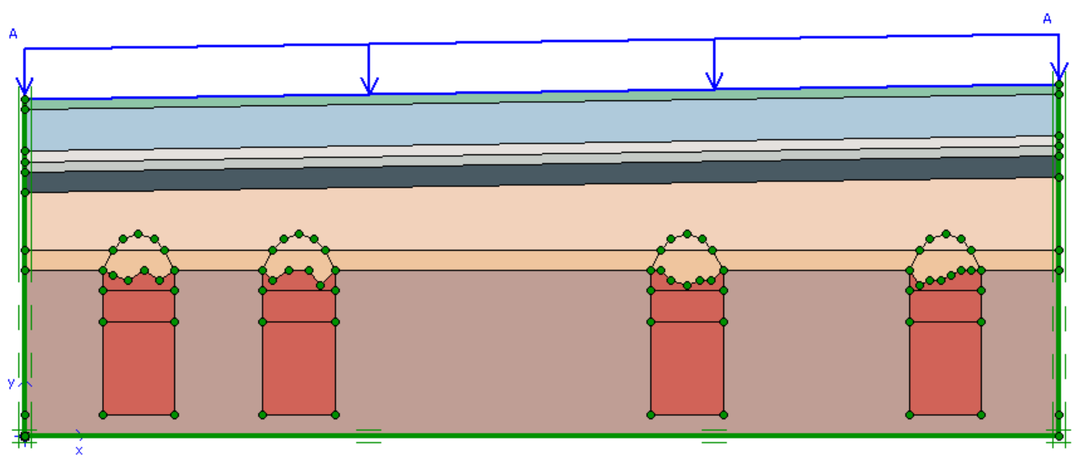

Figure B-4. Model TrenchTrans2. 100-ft wide cross section across trenches 10, 8, 6, and 4 (moving left to right). Grading fill is 5.5-ft thick minimum. This configuration meets the acceptance criteria and no grouted columns are required at any trench.

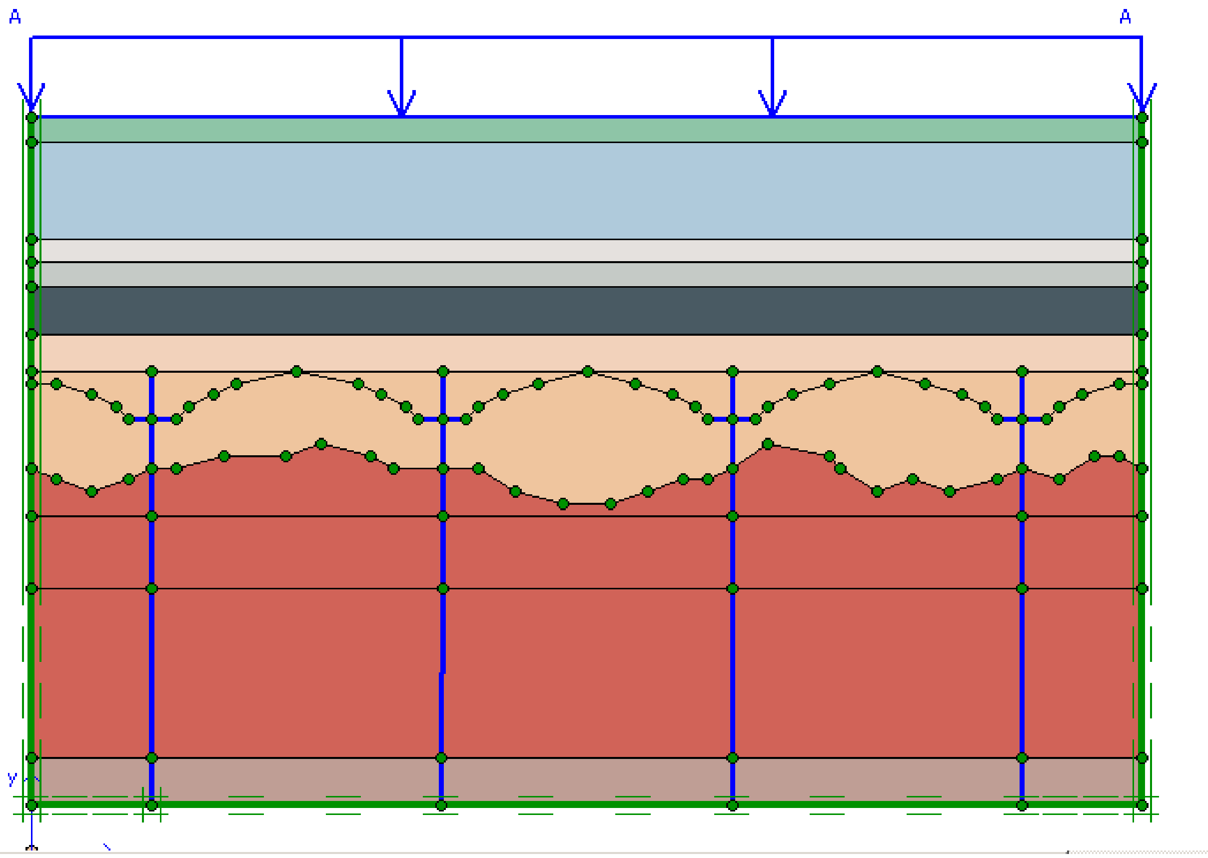

Figure B-5. Model GeneralPit1. 46-ft wide cross section representing pits 1, 2, 3, 5 and 9. Grading fill is 1.5-ft thick. This configuration meets the acceptance criteria with grouted columns spaced at 12 ft each way.

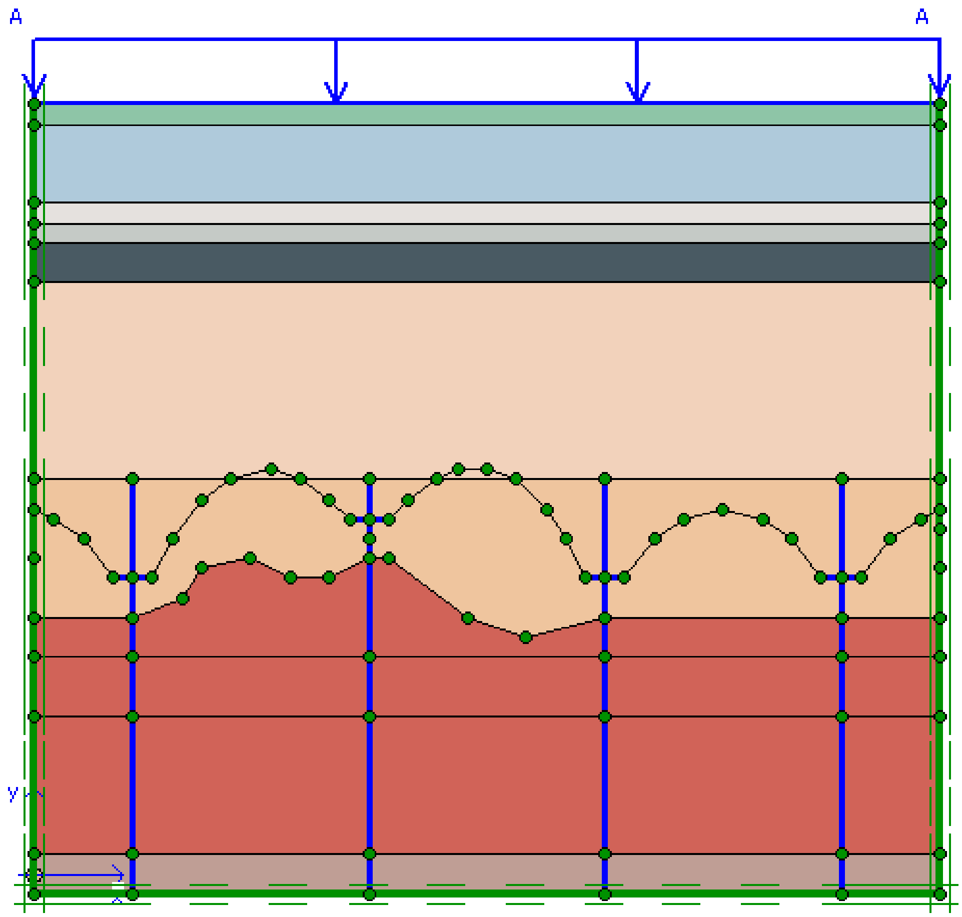

Figure B-6. Model GeneralPit2. 46-ft wide cross section representing pits 4, 6, 10, 11 and 12. Grading fill is 10-ft thick. This configuration meets the acceptance criteria with grouted columns spaced at 12 ft each way.

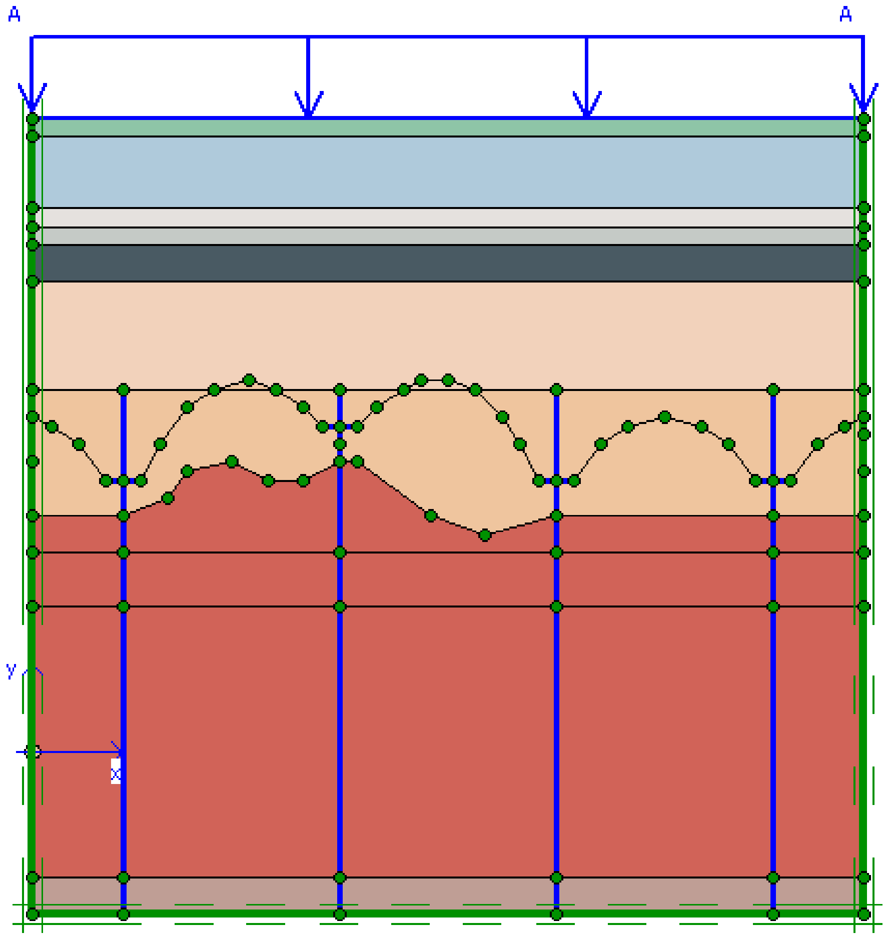

Figure B-7. Model GeneralPit3. 46-ft wide cross section representing pits 17, 18, 19, and 20. Grading fill is 6-ft thick. This configuration meets the acceptance criteria with grouted columns spaced at 12 ft each way.

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Appendix C

Discussion of Material Model and Soil and Waste Parameters Used

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Appendix C

Discussion of Material Model and Soil and Waste Parameters Used

The mechanical behavior of soils may be modeled at various degrees of accuracy. Hooke's law of linear, isotropic elasticity, for example, may be thought of as the simplest available stress-strain relationship. As it involves only two input parameters (i.e., Young's modulus, E, and Poisson's ratio, v) it is generally too crude to capture essential elements of soil and rock behavior. However, for modeling massive structural elements and bedrock layers, linear elasticity tends to be appropriate.

PLAXIS provides for the use of several different soil material models that are appropriate for use in predicting soil and rock behavior. These include the Mohr-Coulomb model, the jointed rock model, the hardening soil model, the soft-soil-creep model, and the soft soil model. The Mohr-Coulomb model was used in this EDF and its use is discussed in more detail below.

The Mohr-Coulomb model is an elastic-plastic model and involves the use of five input parameters (i.e., E and ν for soil elasticity; φ and $\mathbf{c}$ for soil plasticity, and ψ as an angle of dilitancy). This Mohr-Coulomb model represents a good approximation of soil or rock behavior. More precise results can be obtained with the use of other models as listed above, but these require the input of other higher order soil parameters that are not as readily available from standard soils tests.

The actual sources for the soil and rock layers identified for the design of the surface barrier have yet to be finalized. Thus, actual input parameters were not available at the time Revision 0 of this EDF was prepared. Reasonable assumptions, based on the general soil material identified for the preliminary design of the surface barrier,[f] were required to be made. The actual values used for the soil parameters with their respective definitions are tabulated on pages 34 through 26 of this appendix. Pages 37 and 38 contain sources for most of the parameter assumptions. Other parameters were taken from Bowles (1988) and Spangler and Handy (1982).

The waste or waste/soil stiffness and strength parameters were also assumed. The actual values are, of course, highly variable and difficult, if not impossible, to establish with any degree of confidence. The nature of the variability of the stiffness of the waste, currently and as it changes over time, makes the use of any one value for each of the SDA areas analyzed questionable. However, only in a few of the analysis stages were the presence of the waste necessary to consider in the prediction of deformations and stresses. In the case of subsidence, which creates the most important loading condition of the analysis, the change in loading on the waste itself is not considered significant, thus knowing its precise strength and stiffness is not necessary. Still, to give conservative results, a conservation assumption as to the parameters of the waste or waste/soil matrix was made and these parameters are also listed on pages 35 and 36 of this appendix.

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[f] Mattson, E, D., M. D. Ankeny, S. Dwyer, N. Hampton, G. Matthern, B. Pace, A. Parsons, M. Plummer, S. Reese, and J. Waugh, 2004, *Preliminary Design Criteria and Cover Evaluation for the INEEL Subsurface Disposal Area (DRAFT)*, ICP/EXT-04-00216.

Definition of PLAXIS Soil Parameters

γ_{unsat}	=	saturated unit weight
γ_{sat}	=	unsaturated unit weight
k_x	=	horizontal permeability (not used in this analysis)
k_y	=	vertical permeability (not used in this analysis)
ν	=	Poisson's ratio
E_{ref}	=	Young's modulus
c_{ref}	=	cohesion
φ	=	angle of internal soil friction
ψ	=	dilitancy angle
E_{incr}	=	increase of stiffness with depth (not used)
c_{incr}	=	increase of cohesion with depth (not used)
Y_{ref}	=	horizontal permeability
T-Strength	=	tensile strength (set to 0.0 by default for the Mohr-Coulomb model)
R_{inter}	=	interface strength (a value of 1.0 means interface is rigid [i.e. does not influence the strength of the surrounding soil])

PLAXIS - Finite Element Code for Soil and Rock Analyses

PLAXIS 8.x

Project description : General Pit1
User name : Bechtel BWXT Idaho, LLC
Project name :
Output : Soil and Interfaces Info - Mohr-Coulomb

Date : 8/3/2004
Step : 0 Page : 1

ID	Name	Type	γ_{unsat} [lb/ft^3]	γ_{sat} [lb/ft^3]	k_x [ft/hr]	k_y [ft/hr]	ν [-]	E_{ref} [lb/ft^2]
1	Water Storage	Drained	115.0	139.0	0.0000	0.0000	0.34	2.88E5
2	Waste	Undrained	100.0	120.0	0.0000	0.0000	0.35	10000.0
3	Underburden/Native	Undrained	115.0	129.0	0.0000	0.0000	0.35	2.16E5
4	Topsoil	Undrained	115.0	139.0	0.0000	0.0000	0.30	2.16E5
5	Biointrusion Barrier/Gas Venting	Drained	136.0	149.0	0.0000	0.0000	0.20	4.32E6
6	Crushed Gravel	Drained	136.0	149.0	0.0000	0.0000	0.30	2.016E6
7	Existing Overburden	Drained	103.0	129.0	0.0000	0.0000	0.30	4.32E5
8	Grading Fill	Drained	115.0	139.0	0.0000	0.0000	0.30	4.32E5
9	Sand	Drained	121.0	138.0	0.0000	0.0000	0.30	1.008E5

PLAXIS - Finite Element Code for Soil and Rock Analyses

Project description : General Pit1 **PLAXIS 8.x**
User name : Bechtel BWXT Idaho, LLC
Project name : Date : 8/3/2004
Output : Soil and Interfaces Info - Mohr-Coulomb Step : 0 Page : 2

ID	c_{ref} [lb/ft^2]	φ [°]	ψ [°]	E_{incr} [lb/ft^3]	c_{incr} [lb/ft^3]	y_{ref} [ft]	T-Strength [lb/ft^2]	R_{inter} [-]
1	1.54E3	33.5	0.0	0.0	0.0	0.0	0.0	1.00
2	20.0	15.0	0.0	0.0	0.0	0.0	0.0	1.00
3	1.54E3	26.3	0.0	0.0	0.0	0.0	0.0	1.00
4	500.0	30.0	0.0	0.0	0.0	0.0	0.0	1.00
5	0.2	50.0	20.0	0.0	0.0	0.0	0.0	1.00
6	0.2	50.0	20.0	0.0	0.0	0.0	0.0	1.00
7	1.54E3	26.3	0.0	0.0	0.0	0.0	0.0	1.00
8	1.54E3	33.5	0.0	0.0	0.0	0.0	0.0	1.00
9	20.0	33.5	10.0	0.0	0.0	0.0	0.0	1.00

Appendix H

Soil Properties

Bridges ultimately transfer all of their loads to the earth. Unless the foundation is on bedrock, the bridge will transfer loads through the soil. This appendix provides approximate values for several key soil characteristics *(Table H-1; Tables H-2* and *H-3, page H-2;* and *Figure H-1, page H-3).* Due to the large degree of variance in these characteristics, the actual values from field tests should be obtained whenever possible.

Table H-1. Soil Properties

Soil Type	Characteristics	Symbol	Unit Weight (u) (lb/cu ft)	Angle of Internal Friction (θ) (deg)	Soil Bearing Capacity (ksf)
Sand	Loose and dry	SW to SP	89 to 107	31	3
	Loose and damp		99 to 117	31	3
	Loose and saturated		108 to 134	31	3
	Dense and dry		114 to 118	32.5	5
	Dense and damp		124 to 127	32.5	5
	Dense and saturated		134 to 137	32.5	5
	Compact and dry		121 to 127	33.5	10
	Compact and damp		128 to 135	33.5	10
	Compact and saturated		138 to 142	33.5	10
	Sand (sand clay)	SC	129 to 141	22 to 26	5
Gravel	Loose and dry	GW to GP	112 to 118	30	4
	Loose and damp		115 to 122	30	4
	Loose and saturated		136 to 142	30	4
	Dense and dry		136	33.5	12
	Dense and damp		140	33.5	12
	Dense and saturated		149	33.5	12
Clay	Sandy	CL (with sand)	114 to 135	16 to 22	5
	Stiff	CH	—	—	5
	Very stiff		—	—	6
Soil	Organic	OH	69 to 88	22 to 26	3
Rock	Soft and fractured	—	—	—	20
	Hard and solid	—	—	—	40

TABLE 4.4
TYPI[illegible] [illegible]NGES FOR ELASTIC CONSTANTS OF VARIOUS MATERIALS* Hunt, 1986

Material	Young's modulus E_s, tsf, kg/cm²	Poisson's ratio ν
SOILS		
Clay:		
Soft sensitive	20-40 (500s_u)	0.4-0.5
Firm to stiff	40-80 (1000s_u)	(undrained)
Very stiff	80-200 (1500s_u)	
Loess	150-600	0.1-0.3
Silt	20-200	0.3-0.35
Fine sand:		
Loose	80-120	
Medium dense	120-200	0.25
Dense	200-300	
Sand:		
Loose	100-300	0.2-0.35
Medium dense	300-500	
Dense	500-800	0.3-0.4
Gravel:		
Loose	300-800	
Medium dense	800-1000	
Dense	1000-2000	
ROCKS		
Sound, intact igneous and metamorphics	6-10 × 10⁵	0.25-0.33
Sound, intact sandstone and limestone	4-8 × 10⁵	0.25-0.33
Sound, intact shale	1-4 × 10⁵	0.25-0.30
Coal	1-2 × 10⁵	
OTHER MATERIALS		
Wood	1.2-1.5 × 10⁵	
Concrete	2-3 × 10⁵	0.15-0.25
Ice	7 × 10⁵	0.36
Steel	21 × 10⁵	0.28-0.29

Material	E_s
ESTIMATING E_s FROM N (SPT)‡	
Soil type: Silts, sandy silts, slightly cohesive mixtures	$4N_1$
Clean fine to medium sands and slightly silty sands	$7N_1$
Coarse sands and sands with little gravel	$10N_1$
Sandy gravel and gravels	$12N_1$

*After CGS (1978)[4] and Lambe and Whitman (1969).[3] ‡After NAVFAC (1982).[23] NOTE: Use N values corrected for depth N_1.

Table 5-5 Equations for stress-strain modulus E_s by several test methods
E_s in kPa for SPT and units of q_c for CPT; divide kPa by 50 to obtain ksf Bowles, 1982

	SPT	CPT
Sand	$E_s = 500(N + 15)$	$E_s{}^* = 2$ to $4q_c$
	$E_s\ddagger = 18\,000 + 750N$	$E_s\dagger = 2(1 + D_r^2)q_c$
	$E_s = (15\,200$ to $22\,000) \ln N$	
Clayey sand	$E_s = 320(N + 15)$	$E_s = 3$ to $6q_c$
Silty sand	$E_s = 300(N + 6)$	$E_s = 1$ to $2q_c$
Gravelly sand	$E_s = 1200(N + 6)$	
Soft clay		$E_s = 6$ to $8q_c$
Using the undrained shear strength s_u in unit of s_u		
Clay	$I_p > 30$, or organic	$E_s = 100$ to $500s_u$
	$I_p < 30$, or stiff	$E_s = 500$ to $1500s_u$
	$1 < OCR < 2$	$E_s = 800$ to $1200s_u$
	$OCR > 2$	$E_s = 1500$ to $2000s_u$

* Schmertmann (1970) used $2q_c$; in 1974 used 2.5 to $3.5q_c$ [Mitchell and Gardner (1975)].
† Vesic (1970).
‡ From D'Appolonia et al. (1970) (author's equation from Fig. 44).

Table 4-11 Range of properties for selected rock groups; data from several sources Bowles, 1982 ([illegible]

Type of rock	Typical unit wt., pcf	Modulus of elasticity E, ksi*	Poisson's ratio μ	[illegible]mpressive strength, ksi
Basalt	178	7000–13 000	0.27–0.32	25–60
Granite	168	4000–7000	0.26–0.30	10–40
Schist	165	2000–5000	0.18–0.22	5–15
Limestone	165	2000–6000	0.24–0.25	5–25
Porous limestone				1–5
Sandstone	145–150	1000–3000	0.20–0.30	4–20
Shale	100–140	500–2000	0.25–0.28	1–6
Concrete	100–150	Variable		2–6

* Depends heavily on confining pressure.

3.14. Deformation Parameters for Saturated Clays Lee, White & Ingles, 1983

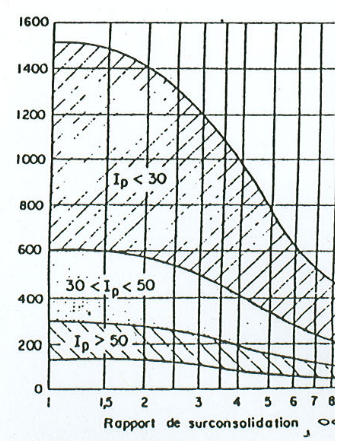
Drainage	*Consolidation History*	*Modulus*	*Poisson's Ratio*
Undrained (Total)	Normal	$E_u/c_u \simeq 200-1000$; $K < 300$, $n \simeq 1.0$	$\nu = 0.5$
	Over	$E_u/\sigma_c' \simeq 100-400$ at OCR-10; $K \simeq 100$ to 500, $n \simeq 0$	$\nu = 0.5$
Drained (Effective)	Normal	E' from m_v (Eqn. 3.34); $K \simeq 5$ to 50, $n \simeq 1.0$	$\nu \simeq 0.35-0.45$
	Over	E' from m_v (Eqn. 3.34); $K \simeq 50$ to 300, $n \simeq 0$	$\nu \simeq 0.30-0.35$, low OCR; $\nu \simeq 0.10-0.30$, high OCR

Note: K and n are constants in Eqn. 3.37.
σ_c' is consolidation stress.

5.3. A Guide to Static Values of Young's Modulus and Poisson's Ratio of Soils and Rocks with Respect to Effective Stresses Lee, White & Ingles, 1983

(Drained) Soil and Rock Type	"Elastic" Parameters E' (kPa)	ν'
Loose well graded sand	1–2.5 × 10⁴	0.2–0.3
Medium dense, well graded sand	2–5 × 10⁴	0.2–0.4
Dense, well graded sand	5–10 × 10⁴	0.2–0.4
Dense, well graded, sand-gravel	10–30 × 10⁴	0.2–0.4
Silt	0.2–2 × 10⁴	0.3–0.35
Soft clay	5–30 × 10²	0.3–0.4
Stiff clay	50–200 × 10²	0.2–0.3
Granite	2–5 × 10⁷	0.1–0.25
Basalt	5–10 × 10⁷	0.1–0.25
Mudstone	2–5 × 10⁷	0.1–0.25
Limestone	1–8 × 10⁷	0.1–0.25

Notes: (i) E' increases with confining pressure.
(ii) ν' increases (approximately linearly) with



Clough & Schmidt 1977

Appendix D

PLAXIS-Generated Report for Model TrenchTrans1

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Appendix D

PLAXIS-Generated Report for Model TrenchTrans1

REPORT

October 25, 2004

User: Bechtel BWXT Idaho, LLC

Title: TrenchTrans1

Table of Contents

1. General Information

Table 1. Units.

Type	Unit
Length	ft
Force	lb
Time	hr

Table 2. Model dimensions.

	min.	max.
X	0.000	100.000
Y	0.000	30.000

Table 3. Model.

Model	Plane strain
Element	15-Noded

2. Geometry

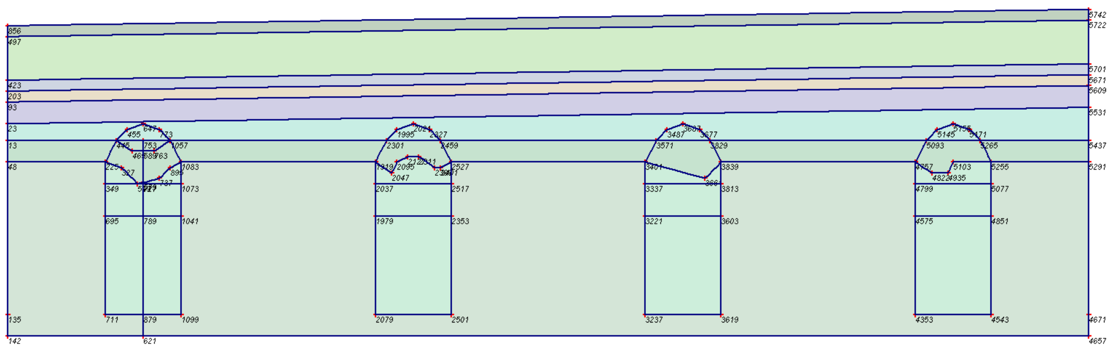

Figure 1. Plot of geometry model with significant nodes.

Table 4. Table of significant nodes.

Node no.	x-coord.	y-coord.	Node no.	x-coord.	y-coord.
142	0.000	0.000	3337	59.000	14.000
4657	100.000	0.000	3813	66.000	14.000
4671	100.000	2.000	4799	84.000	14.000
135	0.000	2.000	5077	91.000	14.000
5291	100.000	16.000	2301	35.000	18.000
48	0.000	16.000	2459	40.000	18.000
5437	100.000	18.000	3829	65.000	18.000
13	0.000	18.000	3571	60.000	18.000
5531	100.000	21.000	445	10.000	18.000
23	0.000	19.500	1057	15.000	18.000
5609	100.000	23.000	5093	85.000	18.000
93	0.000	21.500	5265	90.000	18.000
5671	100.000	24.000	5145	86.000	19.000
203	0.000	22.500	5171	89.000	19.000
5701	100.000	25.000	5155	87.500	19.500
423	0.000	23.500	3487	61.000	19.000
5722	100.000	29.000	3687	62.500	19.500
497	0.000	27.500	3677	64.000	19.000
5742	100.000	30.000	1995	36.000	19.000
856	0.000	28.500	2021	37.500	19.500
225	9.000	16.000	2327	39.000	19.000
711	9.000	2.000	773	14.000	19.000
1083	16.000	16.000	455	11.000	19.000
1099	16.000	2.000	327	10.500	15.500
1919	34.000	16.000	519	12.000	14.000
2079	34.000	2.000	737	14.000	14.500
2527	41.000	16.000	895	15.000	15.500
2501	41.000	2.000	2047	35.500	15.000
3401	59.000	16.000	2401	40.000	15.500
3237	59.000	2.000	2095	36.000	16.000
3839	66.000	16.000	2369	39.500	15.500

Table 4. (continued).

Node no.	x-coord.	y-coord.	Node no.	x-coord.	y-coord.
3619	66.000	2.000	2311	38.000	16.500
5255	91.000	16.000	2127	37.000	16.500
4543	91.000	2.000	3661	64.500	14.500
4757	84.000	16.000	4822	85.500	15.000
4353	84.000	2.000	4935	87.000	15.000
695	9.000	11.000	5103	87.500	16.000
1041	16.000	11.000	589	12.500	17.000
1979	34.000	11.000	621	12.500	0.000
2353	41.000	11.000	879	12.500	2.000
3221	59.000	11.000	789	12.500	11.000
3603	66.000	11.000	727	12.500	14.000
4575	84.000	11.000	579	12.500	14.125
4851	91.000	11.000	465	11.500	17.000
349	9.000	14.000	763	13.500	17.000
1073	16.000	14.000	753	12.500	18.000
2037	34.000	14.000	647	12.500	19.500
2517	41.000	14.000			

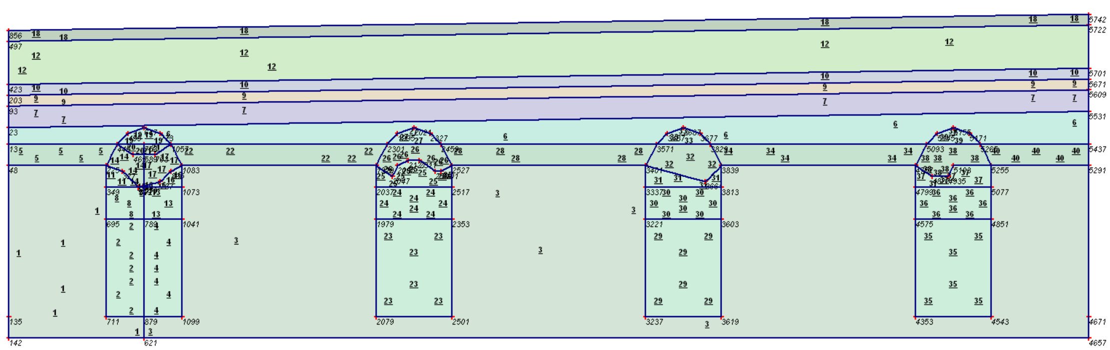

Figure 2. Plot of geometry model with cluster numbers.

Table 5. Table of clusters.

Cluster no.	Nodes
1	142, 135, 48, 225, 711, 695, 349, 621, 879.
2	711, 695, 879, 789.
3	4657, 4671, 5291, 1083, 1099, 1919, 2079, 2527, 2501, 3401, 3237, 3839, 3619, 5255, 4543, 4757, 4353, 1041, 1979, 2353, 3221, 3603, 4575, 4851, 1073, 2037, 2517, 3337, 3813, 4799, 5077, 621, 879.
4	1099, 1041, 879, 789.
5	48, 13, 225, 445.
6	5437, 13, 5531, 23, 2301, 2459, 3829, 3571, 445, 1057, 5093, 5265, 5145, 5171, 5155, 3487, 3687, 3677, 1995, 2021, 2327, 773, 455, 647.
7	5531, 23, 5609, 93.
8	695, 349, 519, 789, 727.
9	5609, 93, 5671, 203.
10	5671, 203, 5701, 423.
11	225, 349, 327, 519.
12	5701, 423, 5722, 497.
13	1041, 1073, 789, 727.
14	225, 445, 327, 519, 589, 579, 465.
15	519, 727, 579.
16	1083, 1073, 737, 895, 727, 579.
17	1083, 1057, 737, 895, 589, 579, 763.
18	5722, 497, 5742, 856.
19	445, 1057, 773, 455, 753, 647.
20	445, 589, 465, 753.
21	1057, 589, 763, 753.
22	1083, 1919, 2301, 1057.
23	2079, 2501, 1979, 2353.
24	1979, 2353, 2037, 2517.
25	1919, 2527, 2037, 2517, 2047, 2401, 2095, 2369, 2311, 2127.
26	1919, 2527, 2301, 2459, 2047, 2401, 2095, 2369, 2311, 2127.
27	2301, 2459, 1995, 2021, 2327.
28	2527, 3401, 2459, 3571.
29	3237, 3619, 3221, 3603.
30	3221, 3603, 3337, 3813.
31	3401, 3839, 3337, 3813, 3661.
32	3401, 3839, 3829, 3571, 3661.
33	3829, 3571, 3487, 3687, 3677.
34	3839, 4757, 3829, 5093.
35	4543, 4353, 4575, 4851.
36	4575, 4851, 4799, 5077.
37	5255, 4757, 4799, 5077, 4822, 4935, 5103.
38	5255, 4757, 5093, 5265, 4822, 4935, 5103.
39	5093, 5265, 5145, 5171, 5155.
40	5291, 5437, 5255, 5265.

3. Structures

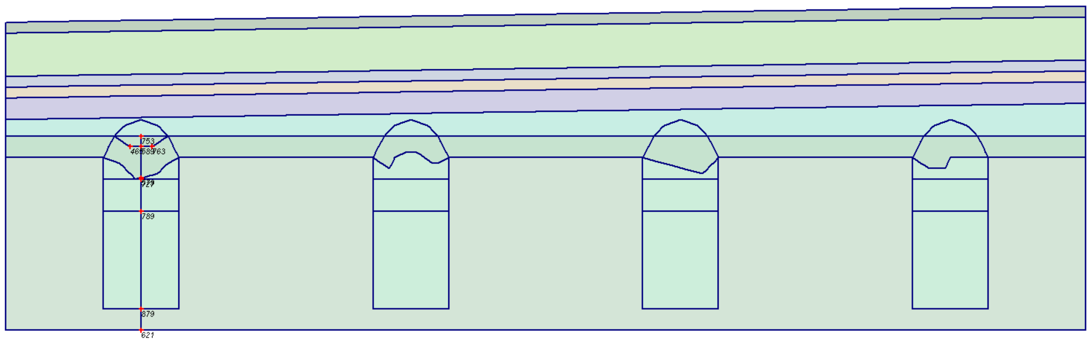

Figure 3. Plot of geometry model with structures.

Table 6. Beams.

Plate no.	Data set	Length [ft]	Nodes
1	2.0 ft dia. grout column	17.000	589, 579, 727, 789, 879, 621.
2	2.0 ft dia. grout column	2.000	465, 589, 763.
3	0.34 ft dia. grout column	1.000	589, 753.

4. Loads and Boundary Conditions

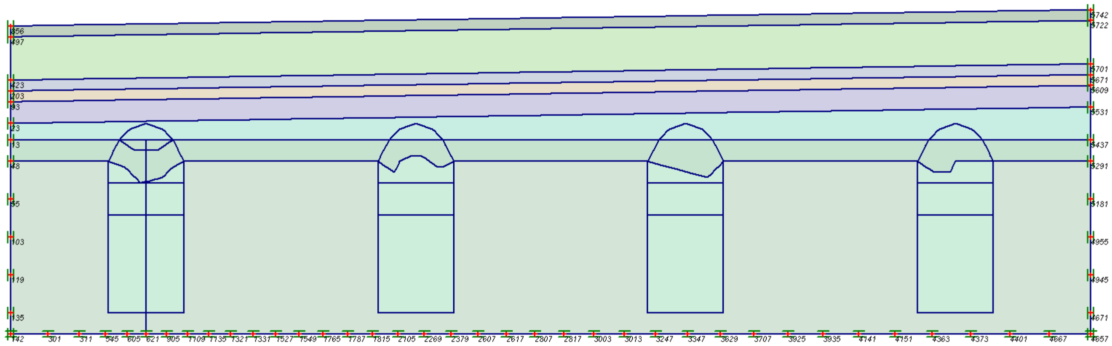

Figure 4. Plot of geometry with loads and boundary conditions.

Table 7. Node fixities.

Node no.	Sign	Horizontal	Vertical	Node no.	Sign	Horizontal	Vertical
142	#	Fixed	Fixed				
4657	#	Fixed	Fixed				
4671	||	Fixed	Free				
135	||	Fixed	Free				
5291	||	Fixed	Free				
48	||	Fixed	Free				
5437	||	Fixed	Free				
13	||	Fixed	Free				
5531	||	Fixed	Free				
23	||	Fixed	Free				
5609	||	Fixed	Free				
93	||	Fixed	Free				
5671	||	Fixed	Free				
203	||	Fixed	Free				
5701	||	Fixed	Free				
423	||	Fixed	Free				
5722	||	Fixed	Free				
497	||	Fixed	Free				
5742	||	Fixed	Free				
856	||	Fixed	Free				
4945	||	Fixed	Free				
4955	||	Fixed	Free				
5181	||	Fixed	Free				
55	||	Fixed	Free				
103	||	Fixed	Free				
119	||	Fixed	Free				

Table 8. Distributed loads A.

Loads no.	First node	Qx [lb/ft/ft]	Qy [lb/ft/ft]	Last node	Qx [lb/ft/ft]	Qy [lb/ft/ft]
1	5742	0.000	0.000	856	0.000	0.000

5. Mesh Data

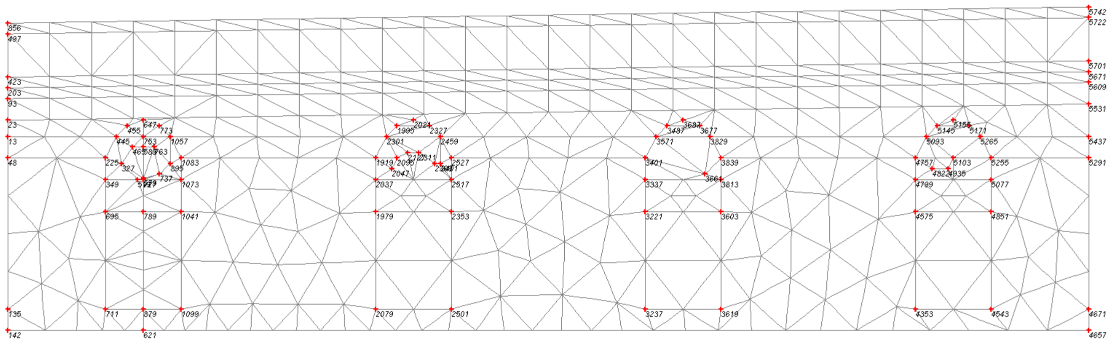

Figure 5. Plot of the mesh with significant nodes.

Table 9. Numbers, type of elements, integrations.

Type	Type of element	Type of integration	Total no.
Soil	15-noded	12-point Gauss	697
Plate	5-node line	4-point Gauss	13

6. Material Data

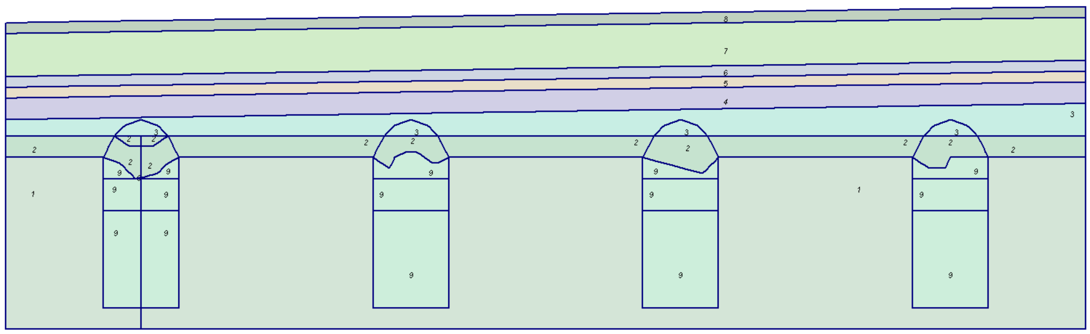

Figure 6. Plot of geometry with material data sets.

Table 10. Soil data sets parameters.

Mohr-Coulomb		1 Underburden/Native	2 Existing Overburden	3 Grading Fill	4 Biointrusion Barrier/Gas Venting
Type		Drained	Drained	Drained	Drained
γ_{unsat}	[lb/ft³]	115.00	103.00	115.00	136.00
γ_{sat}	[lb/ft³]	129.00	129.00	139.00	149.00
k_x	[ft/hr]	0.000	0.000	0.000	0.000
k_y	[ft/hr]	0.000	0.000	0.000	0.000
e_{init}	[-]	0.500	0.500	0.500	0.500
c_k	[-]	1E15	1E15	1E15	1E15
E_{ref}	[lb/ft²]	216000.000	432000.000	432000.000	4320000.000
ν	[-]	0.350	0.300	0.300	0.200
G_{ref}	[lb/ft²]	80000.000	166153.846	166153.846	1800000.000
E_{oed}	[lb/ft²]	346666.667	581538.462	581538.462	4800000.000
c_{ref}	[lb/ft²]	1540.00	1540.00	500.00	0.20
φ	[°]	26.30	26.30	33.50	50.00
ψ	[°]	0.00	0.00	3.50	20.00
E_{inc}	[lb/ft²/ft]	0.00	0.00	0.00	0.00
y_{ref}	[ft]	0.000	0.000	0.000	0.000
$c_{increment}$	[lb/ft²/ft]	0.00	0.00	0.00	0.00
$T_{str.}$	[lb/ft²]	0.00	0.00	0.00	0.00
$R_{inter.}$	[-]	1.00	1.00	1.00	1.00
Interface permeability		Neutral	Neutral	Neutral	Neutral

Table 10. (continued).

Mohr-Coulomb		5 Crushed Gravel	6 Sand	7 Water Storage	8 Topsoil
Type		Drained	Drained	Drained	Drained
γ_{unsat}	[lb/ft³]	136.00	121.00	115.00	115.00
γ_{sat}	[lb/ft³]	149.00	138.00	139.00	139.00
k_x	[ft/hr]	0.000	0.000	0.000	0.000
k_y	[ft/hr]	0.000	0.000	0.000	0.000
e_{init}	[-]	0.500	0.500	0.500	0.500
c_k	[-]	1E15	1E15	1E15	1E15
E_{ref}	[lb/ft²]	2016000.000	100800.000	288000.000	216000.000
ν	[-]	0.300	0.300	0.340	0.300
G_{ref}	[lb/ft²]	775384.615	38769.231	107462.687	83076.923
E_{oed}	[lb/ft²]	2713846.154	135692.308	443283.582	290769.231
c_{ref}	[lb/ft²]	0.20	20.00	1540.00	500.00
φ	[°]	50.00	33.50	33.50	30.00
ψ	[°]	20.00	3.50	3.50	0.00
E_{inc}	[lb/ft²/ft]	0.00	0.00	0.00	0.00
y_{ref}	[ft]	0.000	0.000	0.000	0.000
$c_{increment}$	[lb/ft²/ft]	0.00	0.00	0.00	0.00
$T_{str.}$	[lb/ft²]	0.00	0.00	0.00	0.00
$R_{inter.}$	[-]	1.00	1.00	1.00	1.00
Interface permeability		Neutral	Neutral	Neutral	Neutral

Mohr-Coulomb		9 Trench Waste
Type		Drained
γ_{unsat}	[lb/ft³]	100.00
γ_{sat}	[lb/ft³]	120.00
k_x	[ft/hr]	0.000
k_y	[ft/hr]	0.000
e_{init}	[-]	0.500
c_k	[-]	1E15
E_{ref}	[lb/ft²]	100000.000
ν	[-]	0.300
G_{ref}	[lb/ft²]	38461.538
E_{oed}	[lb/ft²]	134615.385
c_{ref}	[lb/ft²]	100.00
φ	[°]	20.00
ψ	[°]	0.00
E_{inc}	[lb/ft²/ft]	0.00
y_{ref}	[ft]	0.000
$c_{increment}$	[lb/ft²/ft]	0.00
$T_{str.}$	[lb/ft²]	0.00
$R_{inter.}$	[-]	1.00
Interface permeability		Neutral

Table 11. Beam data sets parameters.

No.	Identification	EA [lb/ft]	EI [lbft²/ft]	w [lb/ft/ft]	□ [-]	Mp [lbft/ft]	Np [lb/ft]
1	2.0 ft dia. grout column	7.9613E9	2.6538E9	130.00	0.15	1E15	1E15
2	0.34 ft dia. grout column	2.5815E7	1.8651E5	130.00	0.15	1E15	1E15
3	1.0 ft dia. grout column	2.2331E8	1.3957E7	130.00	0.15	1E15	1E15

7. Calculation Phases

Table 12. List of phases.

Phase	Ph-No.	Start phase	Calculation type	Load input	First step	Last step
Initial phase	0	0		-	0	0
Stage 1	1	0	Plastic	Staged construction	1	4
Stage 1a	2	1	Plastic	Staged construction	5	5
Stage 1b	16	2	Plastic	Staged construction	6	6
Stage 1c	15	16	Plastic	Staged construction	7	7
Stage 1d	14	15	Plastic	Staged construction	8	8
Stage 1e	17	14	Plastic	Staged construction	9	9
Stage 2	13	17	Plastic	Staged construction	10	10
Stage 3	3	13	Plastic	Total multipliers	11	11
Stage 4	4	3	Plastic	Total multipliers	12	37
Stage 5	5	4	Plastic	Total multipliers	38	84
Stage 6	6	5	Plastic	Total multipliers	85	118
Stage 7	7	6	Plastic	Staged construction	119	124
Stage 8	8	7	Plastic	Staged construction	125	132
Stage 9	9	8	Plastic	Total multipliers	133	206
Stage 10	10	9	Plastic	Total multipliers	207	229
Stage 11	11	10	Plastic	Total multipliers	230	285
Stage 12	12	11	Plastic	Total multipliers	286	300

Table 13. Staged construction info.

Ph-No.	Active clusters	Inactive clusters	Active beams	Active geotextiles	Active anchors
0	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				
1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				
2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				
16	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				

Table 13. (continued).

Ph-No.	Active clusters	Inactive clusters	Active beams	Active geotextiles	Active anchors
15	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				
14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				
17	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				
13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				
7	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				
8	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40.				

Table 14. Control parameters 1.

Ph-No.	Additional steps	Reset displacements to zero	Ignore undrained behavior	Delete intermediate steps
1	250	No	No	Yes
2	250	No	No	Yes
16	250	No	No	Yes
15	250	No	No	Yes
14	250	No	No	Yes
17	250	No	No	Yes
13	250	No	No	Yes
3	250	No	No	Yes
4	250	No	No	Yes
5	250	No	No	Yes
6	250	No	No	Yes
7	250	No	No	Yes
8	250	No	No	Yes
9	250	No	No	Yes
10	250	No	No	Yes
11	250	No	No	Yes
12	250	No	No	Yes

Table 15. Control parameters 2.

Ph-No.	Iterative procedure	Tolerated error	Over relaxation	Max. iterations	Desired min.	Desired max.	Arc-Length control
1	Standard	0.010	1.200	60	6	15	Yes
2	Standard	0.010	1.200	60	6	15	Yes
16	Standard	0.010	1.200	60	6	15	Yes
15	Standard	0.010	1.200	60	6	15	Yes
14	Standard	0.010	1.200	60	6	15	Yes
17	Standard	0.010	1.200	60	6	15	Yes
13	Standard	0.010	1.200	60	6	15	Yes
3	Standard	0.010	1.200	60	6	15	Yes
4	Standard	0.010	1.200	60	6	15	Yes
5	Standard	0.010	1.200	60	6	15	Yes
6	Standard	0.010	1.200	60	6	15	Yes
7	Standard	0.010	1.200	60	6	15	Yes
8	Standard	0.010	1.200	60	6	15	Yes
9	Standard	0.010	1.200	60	6	15	Yes
10	Standard	0.010	1.200	60	6	15	Yes
11	Standard	0.010	1.200	60	6	15	Yes
12	Standard	0.010	1.200	60	6	15	Yes

Table 16. Incremental multipliers (input values).

Ph-No.	Displ.	Load A	Load B	Weight	Accel	Time	s-f
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 17. Total multipliers - input values.

Ph-No.	Displ.	Load A	Load B	Weight	Accel	Time	s-f
0	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
1	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
2	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
16	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
15	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
14	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
17	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
13	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
4	1.0000	1.0000	1.0000	1.0400	0.7000	0.0000	1.0000
5	1.0000	1.0000	1.0000	1.0400	-0.7000	0.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
9	1.0000	1.0000	1.0000	1.0000	0.7100	0.0000	1.0000
10	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
11	1.0000	1.0000	1.0000	1.0000	-0.7100	0.0000	1.0000
12	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000

Table 18. Total multipliers - reached values.

Ph-No.	Displ.	Load A	Load B	Weight	Accel	Time	s-f
0	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
1	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
2	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
16	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
15	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
14	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
17	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
13	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
4	1.0000	1.0000	1.0000	1.0400	0.6994	0.0000	1.0000
5	1.0000	1.0000	1.0000	1.0400	-0.7000	0.0000	1.0000
6	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
7	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
8	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
9	1.0000	1.0000	1.0000	1.0000	0.7102	0.0000	1.0000
10	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000
11	1.0000	1.0000	1.0000	1.0000	-0.7099	0.0000	1.0000
12	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000

8. Results for Phase 13

Table 19. Step info phase no: 13.

Step no:	10
Calculation type	PLASTIC
Extrapolation factor	0.000
Relative stiffness	0.095

Table 20. Reached multipliers phase no: 13.

Multipliers	Incremental value	Total value
Prescribed displacements	0.0000	1.0000
Load system A	0.0000	1.0000
Load system B	0.0000	1.0000
Soil weight	0.0000	1.0000
Acceleration	0.0000	0.0000
Strength reduction factor	0.0000	1.0000
Time	0.0000	0.0000

Table 21. Staged construction info phase no: 13.

Staged construction	Incremental value	Total value
Active proportion of total area	0.000	1.000
Active proportion of stage	1.000	1.000

Table 22. Iteration info phase no: 13.

Iter. no.	Global error	Plastic points	Plastic Cap + Hard. points	Inacc. Pl. pts.	Plastic Intf. pts.	Inacc. Intf. pts.	Apex & Tension	Inacc. Apx. pts.
1	0.000	0	0	0	0	0	37	0
2	0.000	0	0	0	0	0	37	0
3	0.000	4	0	0	0	0	37	0
4	0.000	16	0	0	0	0	37	0

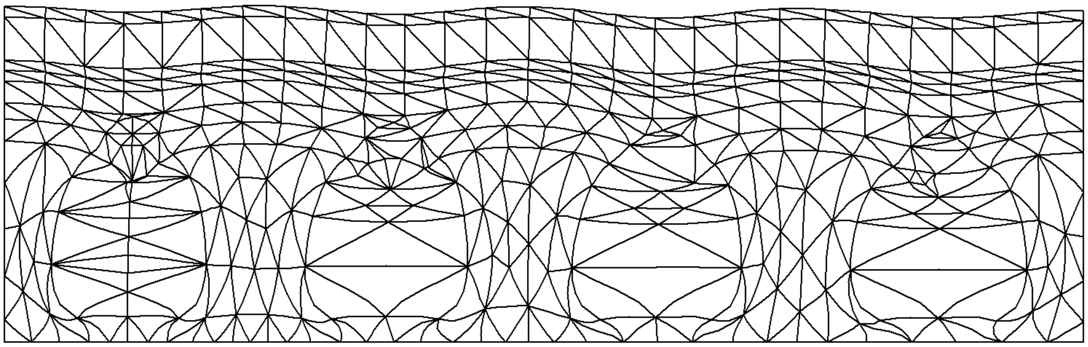

Figure 7. Plot of deformed mesh - step no: 10 - (phase: 13).

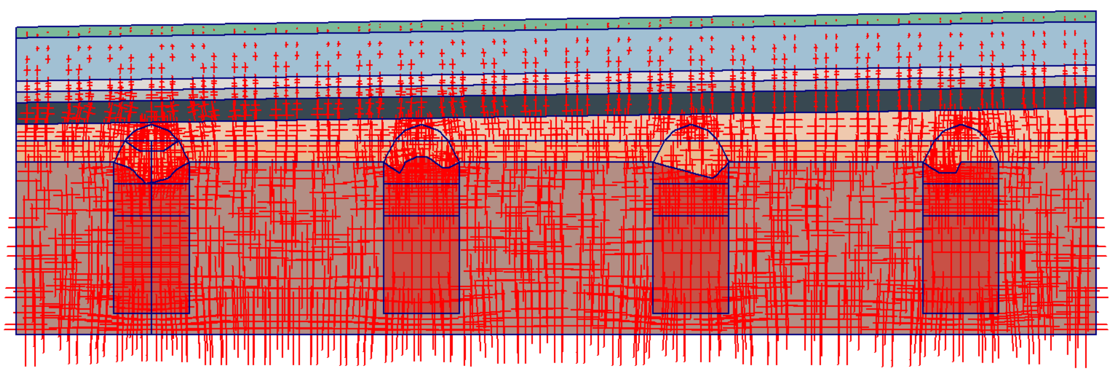

Figure 8. Plot of effective stresses (principal directions) - step no: 10 - (phase: 13).

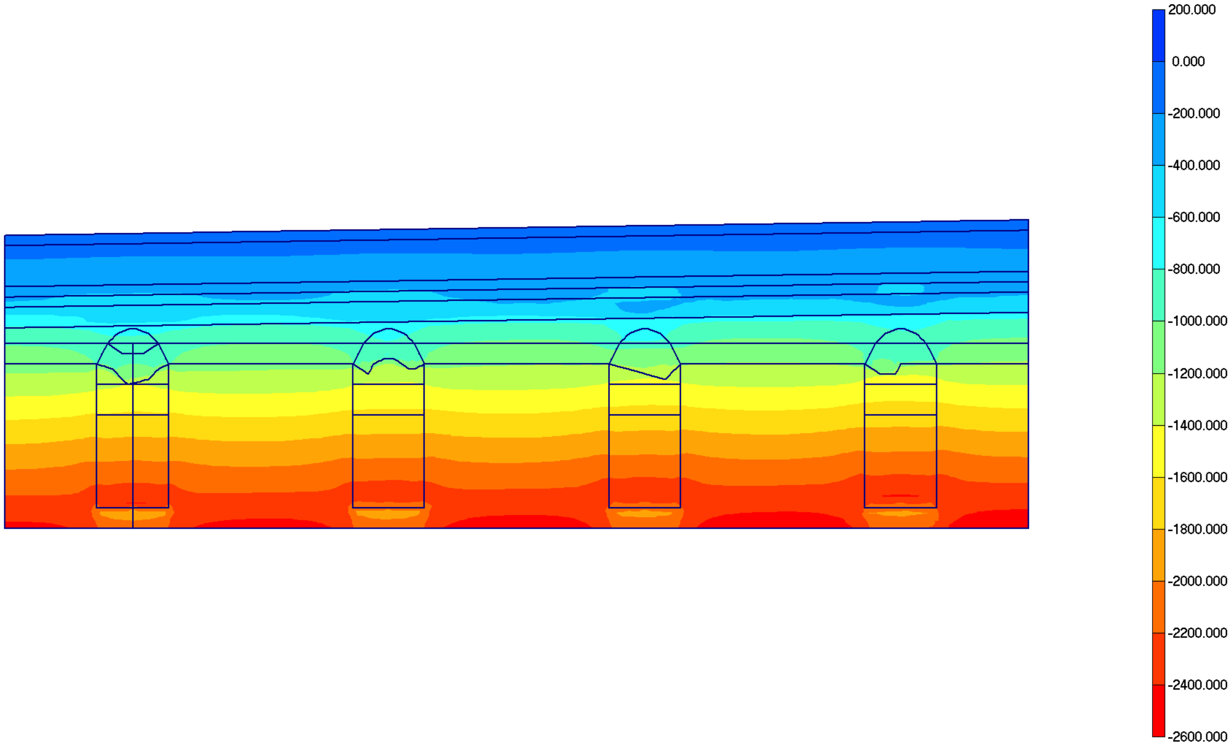

Figure 9. Plot of effective stresses (mean shadings) - step no: 10 - (phase: 13).

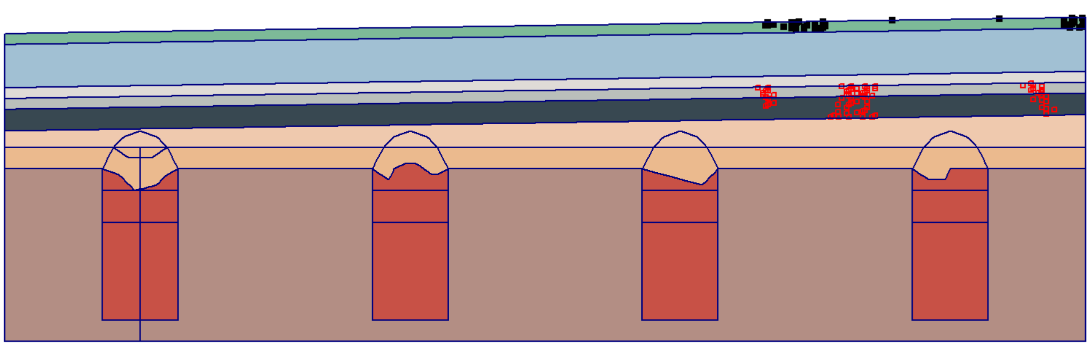

Figure 10. Plot of plastic points - step no: 10 - (phase: 13).

9. Results for Phase 8

Table 23. Step info phase no: 8.

Step no:	132
Calculation type	PLASTIC
Extrapolation factor	0.076
Relative stiffness	0.005

Table 24. Reached multipliers phase no: 8.

Multipliers	Incremental value	Total value
Prescribed displacements	0.0000	1.0000
Load system A	0.0000	1.0000
Load system B	0.0000	1.0000
Soil weight	0.0000	1.0000
Acceleration	0.0000	0.0000
Strength reduction factor	0.0000	1.0000
Time	0.0000	0.0000

Table 25. Staged construction info phase no: 8.

Staged construction	Incremental value	Total value
Active proportion of total area	0.000	1.000
Active proportion of stage	0.079	1.000

Table 26. Iteration info phase no: 8.

Iter. no.	Global error	Plastic points	Plastic Cap + Hard. points	Inacc. Pl. pts.	Plastic Intf. pts.	Inacc. Intf. pts.	Apex & Tension	Inacc. Apx. pts.
1	0.004	65	0	71	0	0	2	1
2	0.004	64	0	4	0	0	2	1

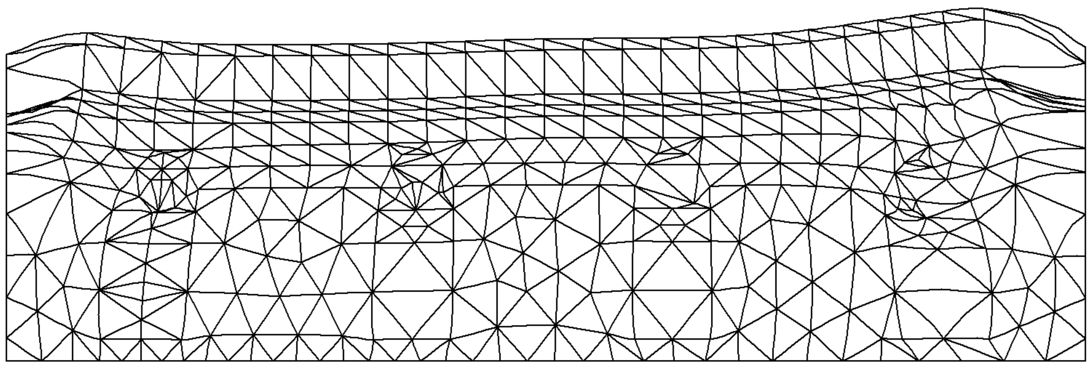

Figure 11. Plot of deformed mesh - step no: 132 - (phase: 8).

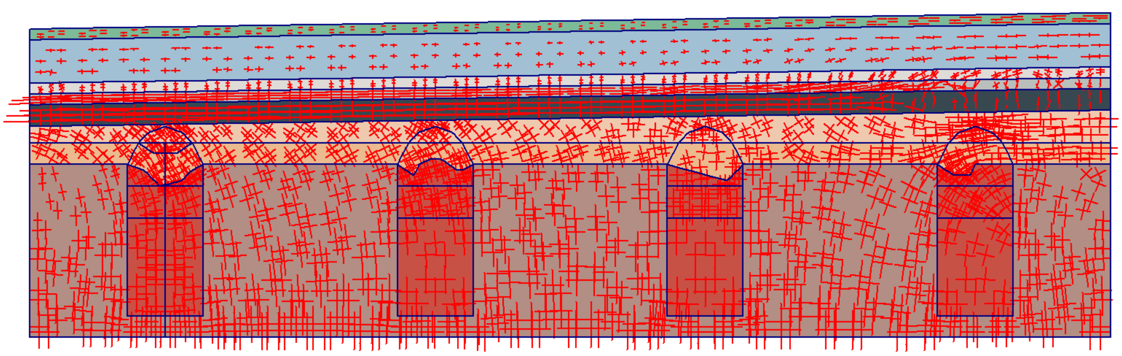

Figure 12. Plot of effective stresses (principal directions) - step no: 132 - (phase: 8).

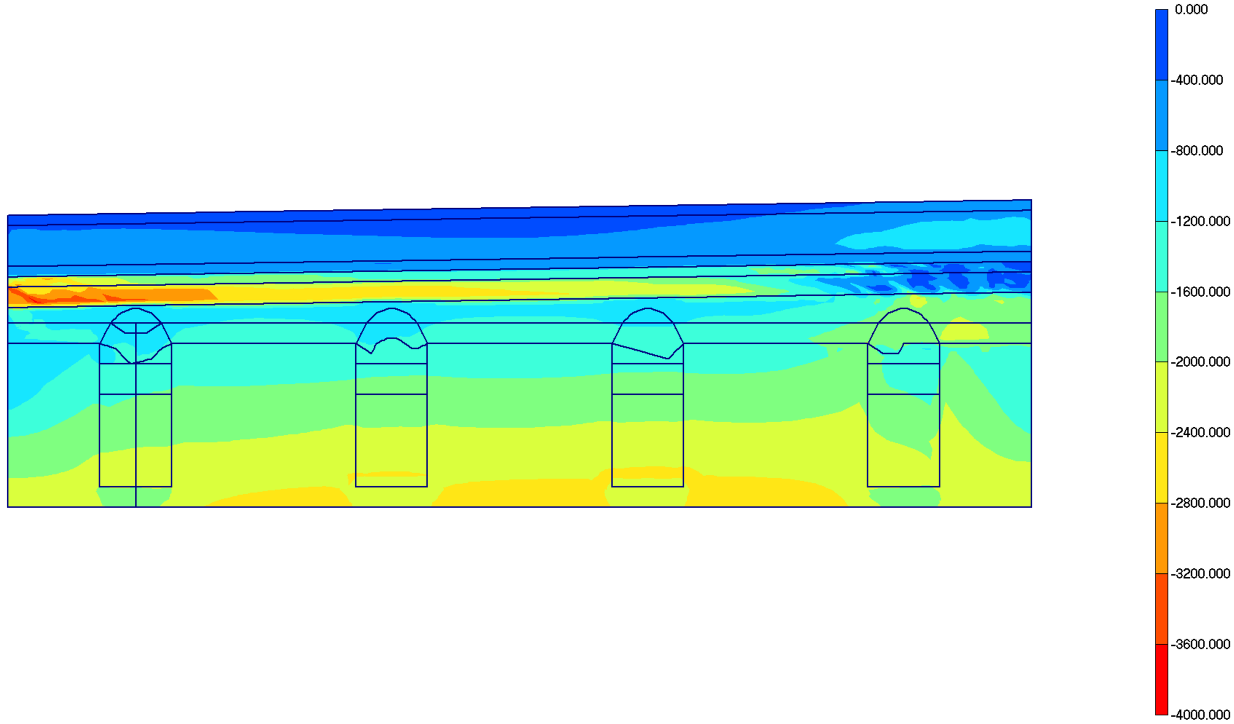

Figure 13. Plot of effective stresses (mean shadings) - step no: 132 - (phase: 8).

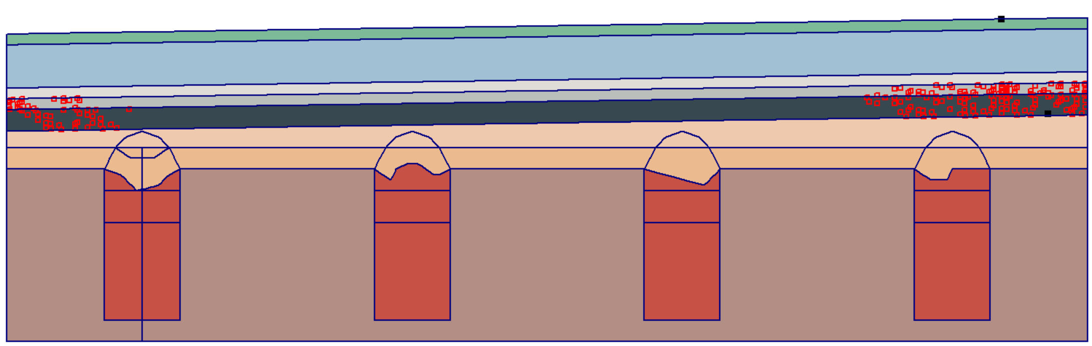

Figure 14. Plot of plastic points - step no: 132 - (phase: 8).

10. Results for Phase 12

Table 27. Step info phase no: 12.

Step no:	300
Calculation type	PLASTIC
Extrapolation factor	0.418
Relative stiffness	0.234

Table 28. Reached multipliers phase no: 12.

Multipliers	Incremental value	Total value
Prescribed displacements	0.0000	1.0000
Load system A	0.0000	1.0000
Load system B	0.0000	1.0000
Soil weight	0.0000	1.0000
Acceleration	0.0122	0.0000
Strength reduction factor	0.0000	1.0000
Time	0.0000	0.0000

Table 29. Staged construction info phase no: 12.

Staged construction	Incremental value	Total value
Active proportion of total area	0.000	1.000
Active proportion of stage	0.000	0.000

Table 30. Iteration info phase no: 12.

Iter. no.	Global error	Plastic points	Plastic Cap + Hard. points	Inacc. Pl. pts.	Plastic Intf. pts.	Inacc. Intf. pts.	Apex & Tension	Inacc. Apx. pts.
1	0.006	251	0	219	0	0	2	2
2	0.006	250	0	14	0	0	2	2

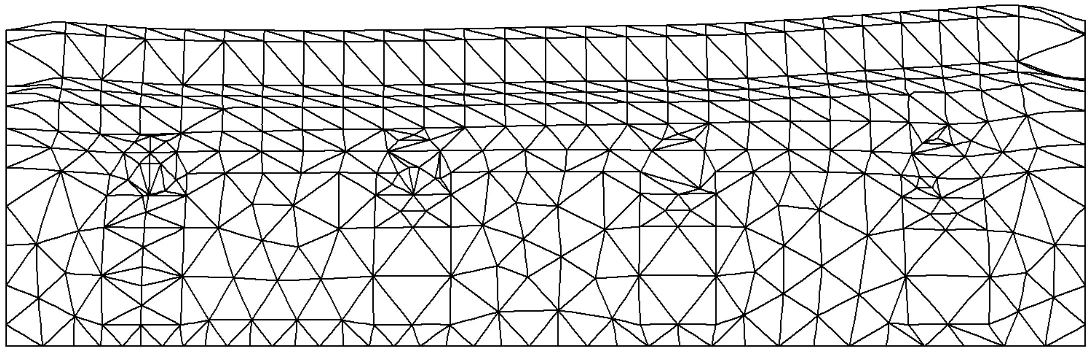

Figure 15. Plot of deformed mesh - step no: 300 - (phase: 12).

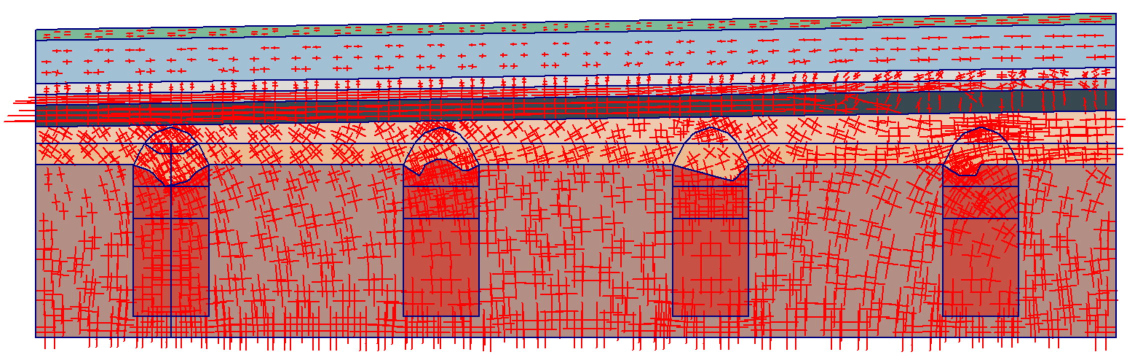

Figure 16. Plot of effective stresses (principal directions) - step no: 300 - (phase: 12).

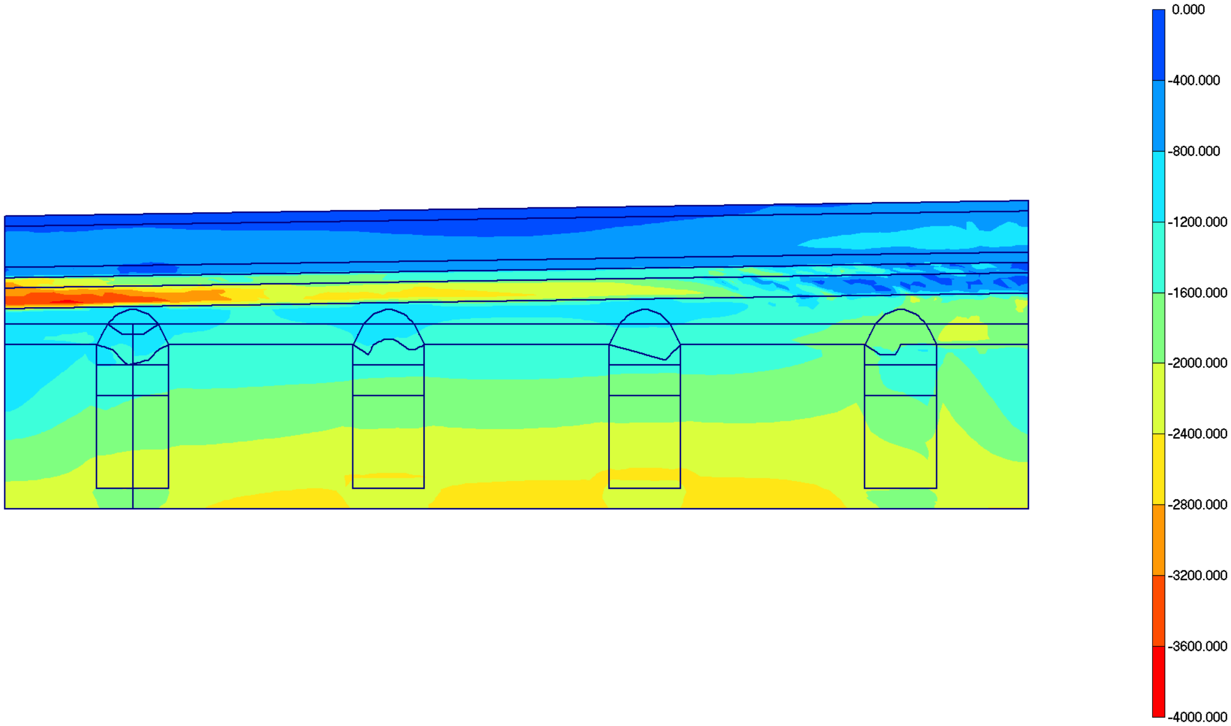

Figure 17. Plot of effective stresses (mean shadings) - step no: 300 - (phase: 12).

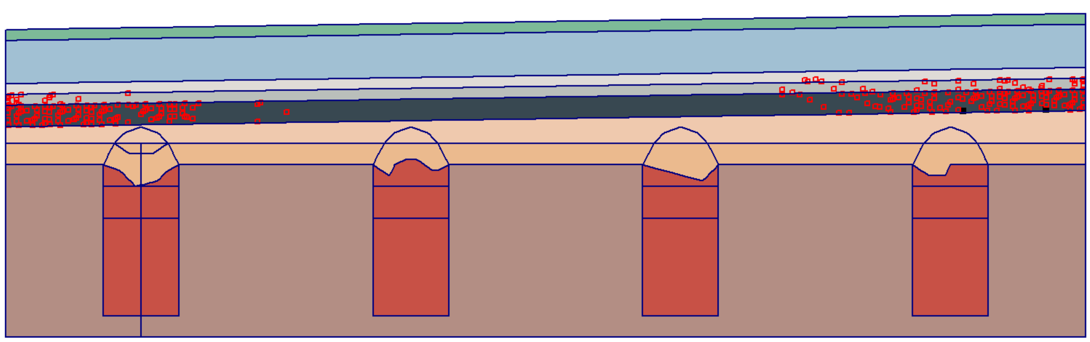

Figure 18. Plot of plastic points - step no: 300 - (phase: 12).

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